Assessments of sugars, organic acids, amino acids, polyphenols, macro and trace elements from fresh tree peony flowers

Jiantao Zhao[a,b†], Yao Xu[c†], Zhijun Zhang[a], Zisha He[a], Weijie Lan[d], Jing Zhang[a,e,f]*

[a] College of Horticulture, Northwest A&F University, Yangling, Shaanxi, 712100, China

[b] Present address: Institu National de la Researche Argonomique, UR1052, Génétique et Amélioration des Fruits et Légumes, 84143 Montfavet Cedex, France

[c] Huai'an Forestry Technology Guidance Station, Qinglian Alley 9, Qingjiangpu District, Huai'an, Jiangsu 223001, China

[d] Institu National de la Researche Argonomique, UMR408 Sécurité et Qualité des Produits d'Origine Végétale, F-84000 Avignon, France.

[e] State Key Laboratory of Crop Stress Biology for Arid Areas, College of Horticulture, Northwest A&F University, Yangling, 712100, China,

[f] Key Laboratory of Protected Horticultural Engineering in Northwest, Ministry of Agriculture, Yangling, China, 3 College of Forestry, Northwest A&F University, Yangling, 712100, China

[†] These two authors contributed equally to the present study.

* To whom correspondence should be addressed

Mail address: College of Horticulture, Northwest A&F University, Yangling, Shaanxi, 712100, China

Email: yyzhj@nwsuaf.edu.cn; Tel.: +86-029-87082613

Abstract

Tree peony flowers are traditional ornamental and medicinal materials in China. In this study, 23 tree peony flowers at a broad color spectrum were analyzed. Gas chromatography-mass spectrometer (GC-MS) revealed that tree peony flowers are rich in sugars and organic acids. Up to 18 amino acids were identified by liquid chromatography-mass spectrometer (LC-MS), including all essential amino acids, except for methionine. The majority of amino acids were significant positively correlated with each other and were significant negatively correlated with glucose, fructose and galactose. A total of 11 polyphenols were identified in these tree fresh peony flowers by LC-MS. There was a high consistency in grouping peony flowers by using sugars and organic acids and amino acids, which differed from that based on color components and polyphenols. Tree peony flowers are also rich in K, Ca, Mg and Fe. In together, peony flowers can be a good resource of health-promoting compounds.

Key words: tree peony flowers; sugars and organic acids; amino acids; polyphenols; GC-MS; LC-MS

1. Introduction

Tree peony (*Paeonia suffruticosa* Andr.), which originates in China, is wildly cultivated in China and then introduced to Japan, Europe and America. It is famous for its diverse cultivars and flower colors as an ornamental plant, but also as a traditional Chinese medical material. Fresh peony flowers can also be viewed as resource of organic food, which has great health benefits (Valente & Pitts, 2017). Tree peony is rich in a diverse of metabolites, and many of them are beneficial for human health. For example, tree peony seeds are rich in unsaturated fatty acids, especially α-linolenic acid (Li et al., 2015; Li et al., 2015; Yu, Du, Yuan, & Hu, 2016), proteins (Gao et al., 2018) and polyphenols (He, Peng, Xiao, Liu, & Xiao, 2013; Zhang, Shi, Ji, Niu, & Zhang, 2017; Zhang, Zhang, Jin, Niu, & Zhang, 2018).

Tree peony flowers, except for its ornamental merits, are also rich in diverse health-promoting compounds, such as flavonoids (Fan, Zhu, Kang, Ma, & Tao, 2012; Li et al., 2009), polyphenols (Xiong et al., 2014), anthocyanins (Jia et al., 2008; Wang et al., 2001), volatile organic components (S. Li, Chen, Xu, Wang, & Wang, 2012) and essential oils (Lei et al., 2018). Total content of phenolic acids in flower was highest of up to 6 categories of vegetables (L. Zhang et al., 2019). Foods resources with rich balanced polyphenols can interact with human gut microbiota, promote a healthier microbial ecology, thereby promoting human health (Tomás-Barberán & Espín, 2019), such as obesity-mediated inflammation and metabolic diseases (Chuang & McIntosh, 2011).

Sugars and organic acids are also crucial for the human health. These compounds, such as fructose, glucose and malic acid, were significantly correlated with consumer preferences and overall likings (Tieman et al., 2017). They were also significantly correlated (positively or negatively) with a diverse of metabolites (Bauchet et al., 2017; Sauvage et al., 2014; Zhao et al., 2016). There are nine essential amino acids that cannot be synthesized by the human body and can only be supplied additionally. However, the essential amino acids in many major crops are presenting in limiting quantities (Galili, Amir, & Fernie, 2016). Supplementation of amino acids, especially essential amino acids, could promote the quality of life (Rondanelli et al., 2011) and health (Bonfili et al., 2017). Some macro and micro elements are also important for human health. For instance, a high K intake is associated with a decrease of blood pressure, stroke-associated mortality and cardiovascular disease, etc. (Weaver, 2013). Early Fe deficiency could have a long-term brain and behavioral consequences (Georgieff, 2011). Supplementation of Mg could attenuate anxiety symptoms (Boyle, Lawton, & Dye, 2017). However, to date, studies on tree peony flowers are only focused on some cultivars and some limited compounds.

Gas chromatography-mass spectrometer (GC-MS) and liquid chromatography-mass spectrometer (LC-MS) have been reliable technique to characterize diverse metabolites. The objectives of this study are as follows: (1) to measure the sugars, organic acids, amino acids, polyphenols, macro and trace elements of 23 different tree peony flowers at a wide color spectrum; (2) to evaluate the correlation patterns among these important compounds; (3) to compare the clustering results of these tree peony flowers between morphological (color components) and nutritional (sugars and organic acids, amino acids and polyphenols) traits.

2. Materials and methods

2.1 Plant Materials

Fresh flowers of 23 tree peony species at the same full blooming stage in 2018 spring were collected from the Peony Garden in Northwest A&F University. Flowers were frozen in liquid nitrogen immediately and then stored at -80 ˚C before use.

2.2 Determination of color components

Color components (L, a and b) were determined by CR-400 (KONICA, CO. Ltd., Tokyo, Japan). Three flowers were randomly selected for each peony variety. Each petal was measured with a colorimeter at the central area of the petals to determine three color space coordinates L, a and b. L (from black to white, 0 to 100) reflects the brightness of the color, 0 for black and 100 for white. a (from green to red, -a to +a) indicates the concentration of the red or green substance, $a > 0$ indicates that the color is reddish, and $a < 0$ indicates that the color is greenish. b (from blue to yellow, -b to +b) reflects the concentration of yellow or blue matter, $b > 0$ means yellowish color, and $b < 0$ means blueish color.

2.3 Determination of sugars and organic acids

Sugars and organic acids were determined using GC-MS according to the method of (Zhao et al., 2016) with modifications. About 1g fresh peony flower was first extracted with 1.4 mL 75% methanol and 100 μL ribitol (international standard) and mixed at 70 ˚C for 30 min at 11000 g. The supernatant was collected and then mixed with 750 μL trichloromethane and 1400 μL ddH_2O and then centrifuged at 4 ˚C for 30 min at 2000 g. About 2 μL supernatant was moved to a new 1.5 mL Eppendorf vial and dried in vacuum dryer for 2 h without heating. Sample were then derivatized with methoxyamine hydrochloride and N-methyl-N-trimethylsilyl- trifluoroacetamide (MSTFA) sequentially (Lisec, Schauer, Kopka, Willmitzer, & Fernie, 2006). After derivatization, the metabolites were analyzed via an Agilent 7890A GC/5795C MS (Agilent Technology, Palo Alto, CA, USA) with an electron ionization source. The temperature program started isothermal at 100 ˚C for 2 min and then increased to 184 ˚C and kept for 2 min. Sugars and organic acids were identified according to the NIST and Wiley database.

2.4 Determination of amino acids

Free amino acids were determined by LC-MS (Q-TRAP5500 and AB SCIEX, McKinley Scientific, USA) coupled with electrospray ion source (ESI). Fresh flower of 1 g was resolved in 200 mL 50% alcohol/water (with 0.1 mol/L HCl). After complete grinding, the mixture was centrifuged for 10 min at 12000 rpm. The supernatant was then filtered with a 0.22 μm injector and collected before LC-MS. Chromatography was performed in an LC-20AD system (Shimadzu, Kyoto, Japan) equipped with a binary solvent delivery system, a deaerator, an autosampler, a column oven and a controller. The mobile phase was a 0.1% aqueous formic acid solution (solvent A) and methanol solution (solvent B), and the flow rate was set to 0.3 mL/min. The gradient elution procedure was as follows: Initially 25% Eluent B was used and linearly increased from 1 min to 5 min to 95% for 1.5 min. It then linearly drops to 25% in 0.1 min until the end. The run time was 10 min and the injection volume was 5 uL. The autosampler was rinsed with acetonitrile/water solution (1:1, v/v) before injection to avoid crystallization. Ion spray voltage, DP, EP and CXP were 5500, 50, 10 and 11V, respectively. CUR, Gas1 and Gas2 pressure were 35, 60 and 65 psi, respectively. The temperature of the turbine gas was set to 600 °C. Amino acids were fragmented and scanned using a multi-reaction monitoring MRM scanning method. The data processing software was Analyst Software v1.6.1. All standard amino acid resolutions were bought from Sigma-Aldrich, USA.

2.5 Determinations of polyphenols

Polyphenols were also determined by the same LC-MS platform. About 1g fresh peony flower was first extracted with 1 mL extract (Methanol: water: formic acid = 25:24:1) in a 2 mL Eppendorf tube and then with ultrasonic oscillation for 30min. The extracts were then centrifuged at 4 ˚C for 30 min at 12000 rpm and the supernatant was filtered through a 0.22 μm organic filter before LC-MS. Chromatography was also performed in an LC-20AD system (Shimadzu, Kyoto, Japan) equipped with a binary solvent delivery system, a deaerator, an autosampler, a column oven and a controller. The separation was carried out on a C18 column (150 × 4.6 mm, 5 μm) at 35 °C. The mobile phase was 0.1% aqueous formic acid (solvent A) and methanol (solvent B), and the flow rate was set to 0.7 mL min-1. The gradient elution procedure was as follows: Initially 25% Eluent B was used and linearly increased from 1 min to 5 min to 95% for 1.5 min. It then linearly drops to 25% in 0.1 min until the end. The run time was 12 min and the injection volume was 5 μL. The autosampler was rinsed with acetonitrile/water solution (1:1, v/v) before injection to avoid crystallization. Ion spray voltage, DP, EP and CXP were -4500, -10 and -16V, respectively. CUR, Gas1 and Gas2 pressure were 35, 60 and 65 psi, respectively. The temperature of the turbine gas was set to 600 °C.

2.6 Determination of metal elements

Metal contents were measured using standard curve line. For K, the standard KNO_3 solution gradient was 1, 2, 4, 6, 8 and 10 mg/L. The standard $NaNO_3$ and $Ca(NO_3)_2$ solution gradient was 1, 2, 3, 4, and 5 mg/L. The standard $Zn(NO_3)_2$ and $Mg(NO_3)_2$ solution gradient was

0.5, 0.75, 1, 1.5 and 2 mg/L. The standard $Cu(NO_3)_2$, $Fe(NO_3)_3$ and $Mn(NO_3)_2$ solution gradient was 0.25, 0.5, 0.75, 1 and 1.5 mg/L. The content of K was measured by flame spectrophotometer (M410; Sherwood Scientific, Cambridge, UK). The Ca and Mg contents were measured by an atomic absorption spectrophotometer (Z-2000; Hitachi Limited, Tokyo, Japan). Trace elements were determined by inductively coupled plasma mass spectrometry (iCAP QICP-MS; Thermo Fisher Scientific, Waltham, MA, USA).

2.7 Statistics

All statistical analyses were performed using R (R Core Team, 2018). Contents of all measured components were expressed as mean ± SD (standard deviation), based on three replicates. Heatmap and clustering analysis was performed using package "Heatmaply" (T. Galili, O'Callaghan, Sidi, & Sievert, 2018) or "ComplexHeatmap" (Gu, Eils, & Schlesner, 2016). Correlation analysis was performed in package "corrplot" (Wei & Simko, 2017) with the default parameters with minor modifications.

3. Results and discussion

3.1. Color profiles

Colors of the measured twenty-three fresh peony flowers ranged from dark purple to white (**Table 1**). Based on the contents of color components (L, a and b), these peonies could be subdivided into four groups (**Fig. S1**). Among these, group I and II were mainly consisted of purple-to-red peonies, while group III was mainly consisted of pink-to-purple peonies. These three groups together formed the colorful peony group. For the last group IV, it included all white peonies and the only yellow peony. These results demonstrated that color components were useful for classification of different cultivars (Wang et al., 2001; Yang et al., 2011).

3.2. Sugars and organic acids

Sugars and organic acids are crucial for the human health. Peony flowers are rich in sugars and organic acids, especially sucrose, glucose, fructose and malic acid (**Table 2**). For glucose, the highest content was observed in Hongxia (36.973 ± 0.435 mg/g), a red peony, while the lowest content was in Morunjuelun (7.968 ± 0.232 mg/g), the only dark purple peony. Fructose and glucose shared a similar content pattern across all peony flowers. These compounds, such as fructose, glucose and malic acid, were significantly correlated with consumer preferences and overall likings (Tieman et al., 2017). Also, they were significantly correlated (positively or negatively) with a diverse of metabolites (Bauchet et al., 2017; Sauvage et al., 2014; Zhao et al., 2016). Correlation analysis revealed that fructose and glucose had a high significant positive correlation ($P < 0.001$), and they were both negative significantly correlated with sucrose ($P < 0.01$) **(Fig. S2A)**. There was a high significant negative correlation between malic acid and sucrose ($P < 0.001$) (**Fig. S2A**). These results demonstrated a comprehensive pattern of sugars and organic acids in peony flowers.

Based on the contents of sugars and organic acids analyzed, these peonies could also be subdivided into four groups (**Fig. S2B**). Some peonies were divided into same groups, such as Lanzikui, Roufurong, Gejinzi and Weizi. However, major differences in grouping were observed for the remaining peonies, compared with the subdivision based on color components. For example, Morunjuelun belonged to color group IV based on color components. However, it formed a single group based on the contents of sugars and organic acids, which was distinct from all the other peonies. These results showed that flower colors and nutritional traits had distinct classification performances. Other factors could also possibly impact the clustering results, such as ecological factors (Zhang et al., 2017).

3.3 Amino acids

There are nine essential amino acids that cannot be synthesized by the human body and can only be supplied additionally. The essential amino acids in many major crops are presenting in limiting quantities (Galili et al., 2016). In this study, up to 18 amino acids were identified in fresh peony flowers (**Supplementary Table 1**). Among these, all essential amino acids were detected, except for methionine. The highest average amino acid content among all peony flowers was detected on glutamine (12.992 ± 3.981 mg/g) and the lowest value was found on cysteine (0.671 ± 0.428 mg/g). For the eight essential amino acids, the highest average value was detected on leucine (6.845 ± 2.605 mg/g), and the lowest was tryptophan (0.919 ± 0.223 mg/g). Similarly, the leucine content was also the highest in the tree peony seeds (Gao et al., 2018). Correlation analysis revealed that the majority of amino acids had a significant ($P < 0.05$) positive correlation (**Fig. 1A**). The main exception was essential amino acid tryptophan, which showed a weak negative correlation with all the remaining amino acids (**Fig. 1A**). Most of these 18 amino acids were significant negatively correlated with glucose, fructose and galactose, including the seven essential amino acids (histidine, isoleucine, leucine, lysine, methionine, threonine and valine). Tryptophan had a weak positive correlation with glucose, fructose and galactose (**Fig. 1A**). The negative correlation showed that it is possible to supply amino acids, and control the sugars at a lower level, which could promote obesity treatment (Kim & Park, 2012).

Using all amino acids, these peonies could also be subdivided into four groups (**Fig. 1B**). This clustering was highly similar for most peonies compared with that based on sugars and organic acids. For existence, Morunjuelun, the only dark purple peony, formed a single group, which was the same as revealed in **Fig. S2B**. Jinyu, Zangzihong, Baixueta, Juanyehong, Xueyingtaohua and Shanhutai both formed the same subgroup. Linghuazhanlu, Shouanhong and Zhihong belonged to the same subgroup, while Nihonghuancai, Weizi, Xiangyu, Dahuhong, Yaohuang, Lanzikui belonged to the same subgroups. Only Hongxia, Shibaihao and Wulongpengsheng were classed into different subgroups. These results demonstrated that classifications based on flower colors and central metabolites had major differences. The results between sugars and organic acids and amino acids had a high consistency. Supplementation of amino acids, especially essential amino acids, could promote the quality of life (Rondanelli et al., 2011) and health (Bonfili et al., 2017). Clustering patterns demonstrated the possibilities to choose certain peony flowers to reach a balanced essential amino acids and non-essential amino acids, which may be a promising anticancer strategy (Bonfili et al., 2017).

3.4 Polyphenols

Peony flowers are rich in flavonoids and polyphenols, with positive correlation with antioxidant activity (Li et al., 2009). A total of 11 polyphenols were identified in these fresh peony flowers (**Table 3**). Among these, the highest content was hydroxybenzoic acid observed in Weizi (25666 ± 1634.93 ng/g), a purple peony. The second highest content of hydroxybenzoic acid was observed in Shanhutai (11529 ± 194.63 ng/g). The average content of hydroxybenzoic acid was also the highest (3477.98 ± 5373.53 ng/g) among all polyphenols. Gentioic acid, syringate and gallic acid had a relatively lower average content among all peony flowers, with 4.57 ± 2.60 ng/g, 4.41 ± 1.25 ng/g, 4.10 ± 0.10 ng/g, respectively. The content of the remaining polyphenols varied in hundreds to thousands folds, such as catechin (135.12-2522.41 ng/g), chlorogenic acid (3.61-1892.22 ng/g), epicatechin (3.94-987.42 ng/g) and p-coumaric acid (8.07-786.97 ng/g). Among these, quercetin, rutin, chlorogenic acid and gallic acid were also been identified in peony yellow flowers (Li et al., 2009). However, the remaining polyphenols were not identified. These results demonstrated that different peony flowers might be a good potential resource of polyphenols. Foods resources with rich balanced polyphenols can interact with human gut microbiota, promote a healthier microbial ecology, thereby promoting human health (Tomás-Barberán & Espín, 2019), such as obesity-mediated inflammation and metabolic diseases (Chuang & McIntosh, 2011).

Some positive significant correlations were observed for these polyphenols (**Fig. 2A**). For example, p-coumaric acid was significantly correlated with both hydroxybenzoic acid and catechin; catechin was significantly correlated with hydroxybenzoic acid; quercetin was significantly correlated with protocatechin; rutin was significantly correlated with chlorogenic acid. Though some weak negative correlations were observed among some polyphenols, none of them reached significance (**Fig. 2A**). The correlations between polyphenols and color components, sugars, organic acids and amino acids were weak to moderate. Among these, some of them reached significance. For existence, color component L was significant negatively correlated with epicatechin, protocatecin and quercetin. a was significant positively correlated with epicatechin and protocatechin. b was significantly correlated with rutin. These results demonstrated a comprehensive correlation between color components and physicochemical compounds (Yang et al., 2011; Zhu et al., 2012). In contrast, p-coumaric acid was significant positively correlated with five essential amino acids, namely methionine, histidine, leucine, lysine, and phenylalanine. Clustering analysis revealed a distinct pattern, compared with that based on color components, sugars and organic acids and amino acids (**Fig. 2B**). Hydroxybenzoic acid, which had the highest content compared with other polyphenols, formed a single chemical group. Weizi and Shanhutai, two peony flowers with high content of hydroxybenzoic acid, formed two distinct groups for all peony flowers. This phenol can be used as a good biomarker in early diagnosis for gastric cancer (Jiang et al., 2016). Therefore fresh peony flowers can be a good resource of polyphenols to promote human health (Tomás-Barberán & Espín, 2019).

3.5 Macro and trace elements

The contents of macro elements (Na, K, Ca and Mg) and trace elements (Fe, Mn, Cu and Zn) were analyzed for different peony flowers (**Table 4**). The highest content macro element was K, ranging from 6.988 mg/g in Yaohuang (a yellow peony) to 28.562 mg/g in Jinpaohong (a purple red peony). The range of Mg ranged from 0.62 mg/g in Shanhutai and 4.932 in Jinpaohong. These two macro elements were significant positively correlated ($P < 0.001$). Na and Ca were significant ($P < 0.05$) positively correlated (**Fig. S3A**). These two elements shared a similar content distribution pattern among different peonies, and an average content of 2.671 mg/g and 3.916 mg/g, respectively. Among the four trace elements, Fe had the highest content, averaged at 0.632 mg/g, ranging from 0.192 mg/g in Shanhutai and 1.133 mg/g in Morunjuelun (The only dark purple peony). Notably, all these trace elements were significant positively correlated with each other ($P < 0.01$) (**Fig. S3A**). A weak to moderate (not significant) negative correlation was observed between macro and trace elements, except Na, which was significant positively correlated with all four trace elements. Clustering analysis revealed that all these peonies could be subdivided into three groups (**Fig. S3B**). A high K intake is associated with a decrease of blood pressure, stroke-associated mortality and cardiovascular disease, etc. (Weaver, 2013). Early Fe deficiency could have a long-term brain and behavioral consequences (Georgieff, 2011). Supplementation of Mg could attenuate anxiety symptoms (Boyle et al., 2017). These results demonstrated that fresh peony flowers can serve as a good resource of macro and trace elements, especially K, Ca, Mg and Fe, in order to promote human health.

4. Conclusions

Peony flowers are a good source of sugars, organic acids, amino acids, polyphenols, macro and trace elements. Clustering analysis based on color components was not consistent with that from sugars and organics, as well as amino acids. However, the clustering between sugars and organic acids and amino acids were highly consistent. A diverse correlation pattern was observed among these chemical compounds. Among these, amino acids were significant positively correlated with each other and were significant negatively correlated with glucose, fructose and galactose. Peony flowers can serve as a good resource of macro and trace elements, especially K, Ca, Mg and Fe. In together, peony flowers can be a good resource of a diverse physiochemical health-promoting compound to improve human health.

Acknowledgements

Zhao J.-T. and Lan W.-J. are supported by the Chinese Scholarship Council (CSC). This study was funded by Shaanxi Key Research Project (2018TSCXL-NY-05-05) and Shaanxi Fruit Industry Funding Project (2017GYZX11).

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary files

Supplementary Table 1. Contents of amino acids detected in fresh tree peony flowers

Supplementary Fig. 1. Clustering analysis of fresh tree peony flowers based on color components.

Supplementary Fig. 2. Correlation (A) and clustering analysis (B) of fresh tree peony flowers based on sugars and organic acids. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Supplementary Fig. 3. Correlation (A) and clustering analysis (B) of fresh tree peony flowers based on macro and trace elements. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

References

Bauchet, G., Grenier, S., Samson, N., Segura, V., Kende, A., Beekwilder, J., … Causse, M. (2017). Identification of major loci and genomic regions controlling acid and volatile content in tomato fruit: implications for flavor improvement. *New Phytologist*, *215*(2), 624–641. https://doi.org/10.1111/nph.14615

Bonfili, L., Cecarini, V., Cuccioloni, M., Angeletti, M., Flati, V., Corsetti, G., … Eleuteri, A. M. (2017). Essential amino acid mixtures drive cancer cells to apoptosis through proteasome inhibition and autophagy activation. *FEBS Journal*, *284*(11), 1726–1737. https://doi.org/10.1111/febs.14081

Boyle, N. B., Lawton, C., & Dye, L. (2017). The Effects of Magnesium Supplementation on Subjective Anxiety and Stress-A Systematic Review. *Nutrients*, *9*(5), 429. https://doi.org/10.3390/nu9050429

Chuang, C.-C., & McIntosh, M. K. (2011). Potential Mechanisms by Which Polyphenol-Rich Grapes Prevent Obesity-Mediated Inflammation and Metabolic Diseases. *Annual Review of Nutrition*, *31*(1), 155–176. https://doi.org/10.1146/annurev-nutr-072610-145149

Fan, J., Zhu, W., Kang, H., Ma, H., & Tao, G. (2012). Flavonoid constituents and antioxidant capacity in flowers of different Zhongyuan tree penoy cultivars. *Journal of Functional Foods*, *4*(1), 147–157. https://doi.org/10.1016/j.jff.2011.09.006

Galili, G., Amir, R., & Fernie, A. R. (2016). The Regulation of Essential Amino Acid Synthesis and Accumulation in Plants. *Annual Review of Plant Biology*, *67*(1), 153–178. https://doi.org/10.1146/annurev-arplant-043015-112213

Galili, T., O'Callaghan, A., Sidi, J., & Sievert, C. (2018). Heatmaply: An R package for creating interactive cluster heatmaps for online publishing. *Bioinformatics*, *34*(9), 1600–1602. https://doi.org/10.1093/bioinformatics/btx657

Gao, L. L., Li, Y. Q., Wang, Z. S., Sun, G. J., Qi, X. M., & Mo, H. Z. (2018). Physicochemical characteristics and functionality of tree peony (*Paeonia suffruticosa* Andr.) seed protein. *Food Chemistry*, *240*, 980–988. https://doi.org/10.1016/j.foodchem.2017.07.124

Georgieff, M. K. (2011). Long-term brain and behavioral consequences of early iron deficiency. *Nutrition Reviews*, *69*, S43–S48. https://doi.org/10.1111/j.1753-4887.2011.00432.x

Gu, Z., Eils, R., & Schlesner, M. (2016). Complex heatmaps reveal patterns and correlations in multidimensional genomic data. *Bioinformatics*, *32*(18), 2847–2849. https://doi.org/10.1093/bioinformatics/btw313

He, C., Peng, Y., Xiao, W., Liu, H., & Xiao, P. (2013). Determination of chemical variability of phenolic and monoterpene glycosides in the seeds of Paeonia species using HPLC and profiling analysis. *Food Chemistry*, *138*(4), 2108–2114. https://doi.org/10.1016/j.foodchem.2012.11.049

Jia, N., Shu, Q. Y., Wang, L. S., Du, H., Xu, Y. J., & Liu, Z. A. (2008). Analysis of petal anthocyanins to investigate coloration mechanism in herbaceous peony cultivars. *Scientia Horticulturae*, *117*(2), 167–173. https://doi.org/10.1016/j.scienta.2008.03.016

Jiang, J., Guo, L., Cai, W., Wang, Y., Zhang, X., Zhang, J., … Xu, L. (2016). A characteristic biosignature for discrimination of gastric cancer from healthy population by high throughput GC-MS analysis. *Oncotarget*, *7*(52), 87496–87510. https://doi.org/10.18632/oncotarget.11754

Kim, K.-H., & Park, Y. (2012). Food Components with Anti-Obesity Effect. *Annual Review of Food Science and Technology*, *2*(1), 237–257. https://doi.org/10.1146/annurev-food-022510-133656

Lei, G., Li, J., Zheng, T., Yao, J., Chen, J., & Duan, L. (2018). Comparative Chemical Profiles of Essential Oils and Hydrolate Extracts from Fresh Flowers of Eight *Paeonia suffruticosa* Andr. Cultivars from Central China. *Molecules*, *23*(12), 3268. https://doi.org/10.3390/molecules23123268

Li, C., Du, H., Liangsheng, W., Shu, Q., Zheng, Y., Xu, Y., … Ge, Y. (2009). Flavonoid composition and antioxidant activity of tree peony (*Paeonia* section *moutan*) yellow flowers. *Journal of Agricultural and Food Chemistry*, *57*(18), 8496–8503. https://doi.org/10.1021/jf902103b

Li, S.-S., Wang, L., Shu, Q., Wu, J., Chen, L., Shao, S., & Yin, D. (2015). Fatty acid composition of developing tree peony (*Paeonia* section *Moutan* DC.) seeds and transcriptome analysis during seed development. *BMC Genomics*, *16*(1), 208. https://doi.org/10.1186/s12864-015-1429-0

Li, S., Chen, L., Xu, Y., Wang, L., & Wang, L. (2012). Identification of floral fragrances in tree peony cultivars by gas chromatography-mass spectrometry. *Scientia Horticulturae*, *142*(142), 158–165. https://doi.org/10.1016/j.scienta.2012.05.015

Li, S., Yuan, R., Chen, L. guang, Wang, L., Hao, X., Wang, L., … Du, H. (2015). Systematic qualitative and quantitative assessment of fatty acids in the seeds of 60 tree peony (*Paeonia* section *Moutan* DC.) cultivars by GC-MS. *Food Chemistry*, *173*, 133–140. https://doi.org/10.1016/j.foodchem.2014.10.017

Lisec, J., Schauer, N., Kopka, J., Willmitzer, L., & Fernie, A. R. (2006). Gas chromatography mass spectrometry-based metabolite profiling in plants. *Nature Protocols*, *1*(1), 387–396. https://doi.org/10.1038/nprot.2006.59

R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.r-project.org/

Rondanelli, M., Opizzi, A., Antoniello, N., Boschi, F., Iadarola, P., Pasini, E., … Dioguardi, F. S. (2011). Effect of essential amino acid supplementation on quality of life, Amino acid profile and strength in institutionalized elderly patients. *Clinical Nutrition*, *30*(5), 571–577. https://doi.org/10.1016/j.clnu.2011.04.005

Sauvage, C., Segura, V., Bauchet, G., Stevens, R., Do, P. T., Nikoloski, Z., … Causse, M. (2014). Genome-Wide Association in Tomato Reveals 44 Candidate Loci for Fruit Metabolic Traits. *Plant Physiology*, *165*(3), 1120–1132. https://doi.org/10.1104/pp.114.241521

Tieman, D., Zhu, G., Resende, M. F. R., Lin, T., Nguyen, C., Bies, D., … Klee, H. (2017). A chemical genetic roadmap to improved tomato flavor. *Science*, *355*(6323), 391–394. https://doi.org/10.1126/science.aal1556

Tomás-Barberán, F. A., & Espín, J. C. (2019). Effect of Food Structure and Processing on (Poly)phenol–Gut Microbiota Interactions and the Effects on Human Health. *Annual Review of Food Science and Technology*, *10*(1), annurev-food-032818-121615. https://doi.org/10.1146/annurev-food-032818-121615

Valente, T., & Pitts, S. (2017). Organic food in the Diet: Exposure and health implications. *Annu. Rev. Public Health*, *38*, 295–313. https://doi.org/10.1146/annurev-publhealth

Wang, L.-S., Shiraishi, A., Hashimoto, F., Aoki, N., Shimizu, K., & Sakata, Y. (2001). Analysis of Petal Anthocyanins to Investigate Flower Coloration of Zhongyuan (Chinese) and Daikon Island (Japanese) Tree Peony Cultivars. *Journal of Plant Research*, *114*(1), 33-43. https://doi.org/10.1007/pl00013966

Weaver, C. M. (2013). Potassium and Health. *Advances in Nutrition*, *4*(3), 368S–377S. https://doi.org/10.3945/an.112.003533

Wei, T., & Simko, V. (2017). R package “corrplot”: Visualization of a Correlation Matrix (Version 0.84). https://github.com/taiyun/corrplot

Xiong, L., Yang, J., Jiang, Y., Lu, B., Hu, Y., Zhou, F., … Shen, C. (2014). Phenolic Compounds and Antioxidant Capacities of 10 Common Edible Flowers from China. *Journal of Food Science*, *79*(4), C517–C525. https://doi.org/10.1111/1750-3841.12404

Yang, R., Xu, Y., He, Q., Wang, L., Zhu, S., Wang, M., … Shen, Y. (2011). Natural Variation in Petal Color in *Lycoris longituba* Revealed by Anthocyanin Components. *PLoS ONE*, *6*(8), e22098. https://doi.org/10.1371/journal.pone.0022098

Yu, S., Du, S., Yuan, J., & Hu, Y. (2016). Fatty acid profile in the seeds and seed tissues of *Paeonia* L. species as new oil plant resources. *Scientific Reports*, *6*(1), 26944. https://doi.org/10.1038/srep26944

Zhang, L., Li, Y., Liang, Y., Liang, K., Zhang, F., Xu, T., … Lu, B. (2019). Determination of phenolic acid profiles by HPLC-MS in vegetables commonly consumed in China. *Food Chemistry*, *276*, 538–546. https://doi.org/10.1016/J.FOODCHEM.2018.10.074

Zhang, X.-X., Shi, Q.-Q., Ji, D., Niu, L.-X., & Zhang, Y.-L. (2017). Determination of the phenolic content, profile, and antioxidant activity of seeds from nine tree peony (*Paeonia* section *Moutan* DC.) species native to China. *Food Research International*, *97*, 141–148. https://doi.org/10.1016/j.foodres.2017.03.018

Zhang, X. X., Zhang, G., Jin, M., Niu, L. X., & Zhang, Y. L. (2018). Variation in Phenolic Content, Profile, and Antioxidant Activity of Seeds among Different *Paeonia ostii* Cultivated Populations in China. *Chemistry and Biodiversity*, *15*(5), e1800093.

https://doi.org/10.1002/cbdv.201800093

Zhao, J., Xu, Y., Ding, Q., Huang, X., Zhang, Y., Zou, Z., … Zhang, J. (2016). Association Mapping of Main Tomato Fruit Sugars and Organic Acids. *Frontiers in Plant Science*, *7*, 1286. https://doi.org/10.3389/fpls.2016.01286

Zhu, M., Zheng, X., Shu, Q., Li, H., Zhong, P., Zhang, H., … Wang, L. (2012). Relationship between the composition of flavonoids and flower colors variation in tropical water lily (nymphaea) cultivars. *PLoS ONE*, *7*(4), e34335. https://doi.org/10.1371/journal.pone.0034335

Figures captions

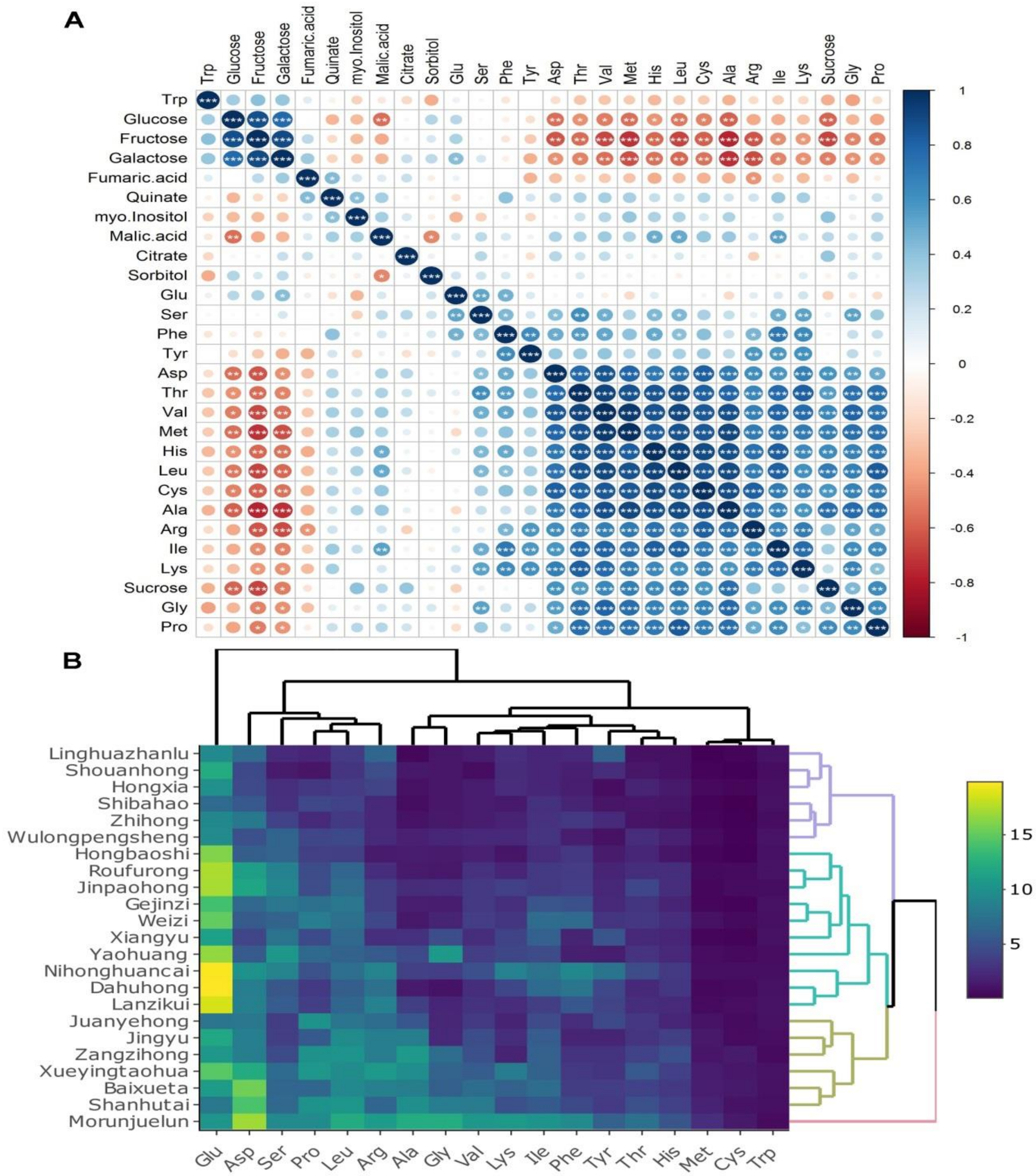

Fig. 1. Correlation (A) and clustering analysis (B) of fresh tree peony flowers based on amino acids. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

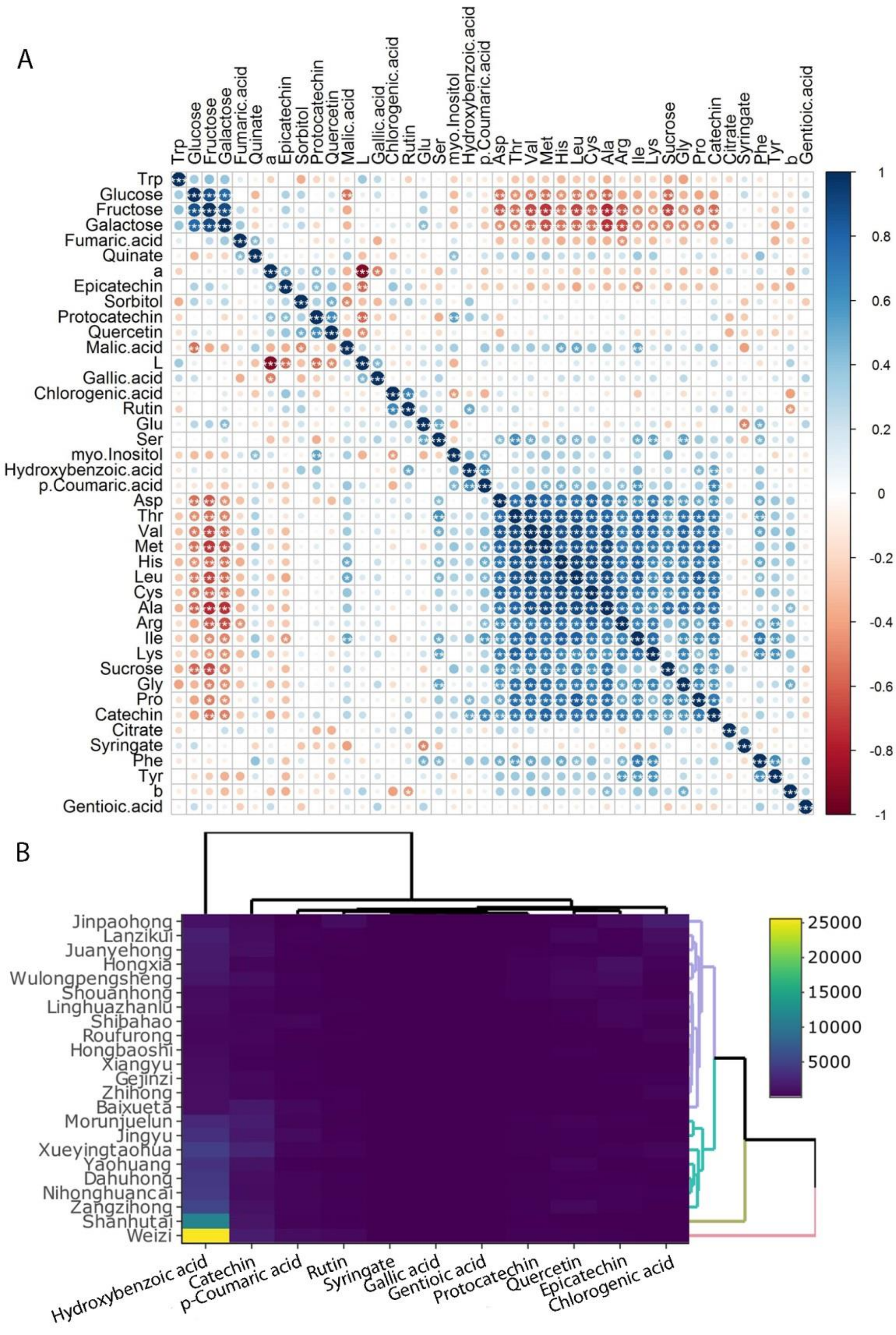

Fig. 2. Correlation (A) and clustering analysis (B) of fresh tree peony flowers based on polyphenols. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Table 1. Color components of different fresh peony flowers

Accession	Color	L	a	b
Morunjuelun	Dark purple	35.049 ± 0.625	50.032 ± 2.156	10.700 ± 1.523
Gejinzi	Purple	64.198 ± 4.168	41.320 ± 4.830	-16.262 ± 1.648
Linghuazhanlu	Pink purple	73.641 ± 8.026	33.868 ± 11.861	-9.536 ± 2.097
Lanzikui	Pink purple	72.178 ± 5.794	38.363 ± 8.498	-8.903 ± 1.662
Jinpaohong	Purple red	47.643 ± 1.527	56.526 ± 2.004	-12.61 ± 2.788
Weizi	Purple red	65.415 ± 6.389	41.224 ± 9.492	-13.293 ± 3.428
Hongxia	Purple red	39.185 ± 2.833	53.993 ± 2.547	-3.420 ± 2.849
Zangzihong	Purple red	42.049 ± 1.227	57.128 ± 1.002	0.303 ± 5.162
Wulongpengsheng	Purple red	39.860 ± 1.139	56.887 ± 1.421	2.832 ± 1.268
Juanyehong	Deep red	61.058 ± 3.265	53.474 ± 3.069	0.377 ± 3.148
Shouanhong	Red	40.946 ± 3.680	61.799 ± 1.355	-9.101 ± 3.523
Hongbaoshi	Red	66.804 ± 3.637	47.354 ± 3.699	7.740 ± 4.262
Dahuhong	Red	69.462 ± 2.618	47.181 ± 4.399	10.382 ± 4.405
Roufurong	Deep pink	80.200 ± 1.598	26.623 ± 7.579	-1.577 ± 1.556
Shanhutai	Pink red	70.478 ± 2.660	45.590 ± 4.409	9.197 ± 3.528
Xueyingtaohua	Pink red	96.138 ± 1.670	3.316 ± 2.928	4.519 ± 0.663
Nihonghuancai	Magenta	67.717 ± 4.201	44.672 ± 4.775	7.208 ± 4.158
Zhihong	Magenta	66.057 ± 1.993	47.324 ± 4.514	11.844 ± 4.116
Shibahao	pink	69.094 ± 8.063	39.674 ± 9.396	-3.809 ± 2.517
Yaohuang	Yellow	97.481 ± 0.486	-2.067 ± 0.303	10.096 ± 0.703
Xiangyu	White	97.529 ± 0.626	-0.871 ± 0.188	7.195 ± 0.445
Jingyu	White	96.214 ± 0.850	0.423 ± 0.605	6.270 ± 0.525
Baixueta	White	96.525 ± 0.686	0.134 ± 0.418	7.561 ± 0.741

Table 2. Sugars and organic acids in fresh peony flowers

Accession	Fructose	Glucose	Sucrose	Galtose	Sorbitol	myo-Inositol	Malic acid	Fumaric acid	Citrate	Quinate
Morunjuelun	6.012 ± 0.618	7.968 ± 0.232	10.597 ± 0.420	0.624 ± 0.023	0.785 ± 0.065	0.348 ± 0.027	2.234 ± 0.220	0.045 ± 0.006	0.005 ± 0.001	0.083 ± 0.007
Gejinzi	21.499 ± 0.846	22.212 ± 0.219	5.967 ± 0.645	3.56 ± 0.335	0.329 ± 0.023	0.299 ± 0.012	2.019 ± 0.133	0.093 ± 0.019	0.015 ± 0.002	0.068 ± 0.009
Linghuazhanlu	22.005 ± 0.647	24.155 ± 0.827	4.639 ± 0.373	2.876 ± 0.222	0.213 ± 0.014	0.198 ± 0.045	0.829 ± 0.02	0.038 ± 0.004	0.005 ± 0.000	0.053 ± 0.004
Lanzikui	26.501 ± 1.570	35.032 ± 0.494	4.665 ± 0.146	4.093 ± 0.217	1.252 ± 0.141	0.161 ± 0.008	0.342 ± 0.050	0.035 ± 0.005	0.002 ± 0.000	0.028 ± 0.003
Jinpaohong	21.726 ± 2.041	23.617 ± 1.875	7.748 ± 0.597	3.549 ± 0.37	1.055 ± 0.091	0.182 ± 0.014	1.92 ± 0.088	0.037 ± 0.007	0.022 ± 0.001	0.027 ± 0.004
Weizi	28.034 ± 0.776	30.470 ± 0.373	6.650 ± 1.214	4.216 ± 0.179	1.275 ± 0.119	0.359 ± 0.034	1.721 ± 0.173	0.069 ± 0.005	0.007 ± 0.001	0.054 ± 0.007
Hongxia	30.934 ± 1.034	36.973 ± 0.435	3.817 ± 0.109	3.946 ± 0.223	1.095 ± 0.149	0.336 ± 0.018	0.695 ± 0.022	0.062 ± 0.008	0.004 ± 0.001	0.075 ± 0.003
Zangzihong	17.821 ± 0.397	16.955 ± 0.101	11.689 ± 1.241	1.897 ± 0.148	0.415 ± 0.040	0.332 ± 0.011	2.462 ± 0.375	0.042 ± 0.003	0.008 ± 0.004	0.058 ± 0.002
Wulongpengsheng	29.434 ± 0.879	29.696 ± 2.091	4.499 ± 0.262	3.533 ± 0.362	0.961 ± 0.067	0.252 ± 0.026	0.553 ± 0.033	0.035 ± 0.008	0.003 ± 0.000	0.035 ± 0.005
Juanyehong	15.643 ± 0.47	19.405 ± 1.225	8.657 ± 0.233	1.742 ± 0.105	0.312 ± 0.007	0.175 ± 0.011	1.182 ± 0.037	0.042 ± 0.004	0.001 ± 0.001	0.036 ± 0.01
Shouanhong	18.109 ± 0.234	20.695 ± 4.988	6.444 ± 5.077	2.384 ± 0.691	0.84 ± 0.351	0.302 ± 0.083	0.454 ± 0.066	0.032 ± 0.009	0.004 ± 0.002	0.018 ± 0.017
Hongbaoshi	26.781 ± 1.23	22.554 ± 0.95	7.646 ± 0.884	4.103 ± 0.496	0.285 ± 0.028	0.287 ± 0.021	2.335 ± 0.339	0.141 ± 0.013	0.019 ± 0.002	0.056 ± 0.007
Dahuhong	25.285 ± 1.328	31.534 ± 1.472	2.837 ± 0.303	3.153 ± 0.207	0.062 ± 0.006	0.22 ± 0.031	2.349 ± 0.26	0.024 ± 0.005	0.004 ± 0.001	0.041 ± 0.005
Roufurong	27.318 ± 1.761	23.865 ± 1.776	9.28 ± 0.253	4.379 ± 0.468	0.259 ± 0.028	0.226 ± 0.019	1.701 ± 0.086	0.045 ± 0.009	0.005 ± 0.000	0.038 ± 0.004
Shanhutai	17.386 ± 1.179	27.536 ± 0.212	14.95 ± 0.346	3.087 ± 0.191	0.776 ± 0.025	0.335 ± 0.002	0.594 ± 0.007	0.013 ± 0.000	0.031 ± 0.002	0.03 ± 0.003
Xueyingtaohua	14.729 ± 0.575	20.188 ± 0.913	10.463 ± 0.586	1.832 ± 0.123	0.514 ± 0.065	0.228 ± 0.037	1.500 ± 0.046	0.033 ± 0.004	0.003 ± 0.001	0.049 ± 0.004
Nihonghuancai	28.95 ± 1.629	31.746 ± 1.458	7.321 ± 0.317	3.453 ± 0.159	1.022 ± 0.038	0.162 ± 0.009	0.816 ± 0.047	0.042 ± 0.004	0.007 ± 0.002	0.054 ± 0.001

Zhihong	21.249 ± 4.195	21.564 ± 3.637	6.722 ± 0.465	3.128 ± 0.603	1.116 ± 0.259	0.179 ± 0.010	0.964 ± 0.010	0.05 ± 0.006	0.009 ± 0.004	0.055 ± 0.008
Shibahao	28.753 ± 1.643	33.154 ± 1.713	6.798 ± 0.011	3.472 ± 0.331	0.173 ± 0.006	0.227 ± 0.016	0.493 ± 0.076	0.071 ± 0.004	0.007 ± 0.002	0.036 ± 0.005
Yaohuang	26.263 ± 0.575	32.878 ± 0.673	6.211 ± 0.136	3.854 ± 0.120	1.252 ± 0.119	0.117 ± 0.151	0.896 ± 0.078	0.04 ± 0.002	0.008 ± 0.001	0.02 ± 0.003
Xiangyu	27.456 ± 0.958	30.353 ± 1.378	2.995 ± 0.126	3.153 ± 0.437	0.123 ± 0.005	0.237 ± 0.024	2.268 ± 0.250	0.021 ± 0.002	0.003 ± 0.002	0.031 ± 0.003
Jingyu	12.113 ± 0.305	17.119 ± 0.838	14.628 ± 0.317	1.586 ± 0.042	0.412 ± 0.006	0.353 ± 0.014	2.834 ± 0.216	0.029 ± 0.004	0.004 ± 0.002	0.036 ± 0.008
Baixueta	17.813 ± 0.476	16.852 ± 0.37	8.376 ± 0.331	2.513 ± 0.109	0.363 ± 0.035	0.23 ± 0.01	2.83 ± 0.119	0.04 ± 0.002	0.008 ± 0.003	0.059 ± 0.005

Table 3. Lists of polyphenols identified in fresh peony flowers

Accession	Catechin	Chlorogenic acid	Rutin	Epicatechin	Protocatechin	Hydroxybenzoic acid	Quercetin	Gentioic acid	Syringate	p-Coumaric acid	Gallic acid
Morunjuelun	1335.68 ± 24.54	3.92 ± 0.19	49.52 ± 3.85	13.65 ± 1.97	35.93 ± 0.6	11528.76 ± 1369.12	17.27 ± 1.05	6.59 ± 0.24	7.61 ± 0.5	206.65 ± 18.5	4.08 ± 0.03
Gejinzi	605.92 ± 4.13	1892.22 ± 75.01	745.16 ± 27.61	779.6 ± 15.94	3.99 ± 0.03	1171.12 ± 85.95	41.44 ± 2.91	4.93 ± 0.05	3.9 ± 0.06	8.07 ± 0.72	3.99 ± 0.03
Linghuazhanlu	2522.41 ± 70.96	451.28 ± 17.47	214.57 ± 8.5	138.98 ± 3.81	72.77 ± 3.25	4582.45 ± 104.42	66.7 ± 3.47	1.4 ± 0.24	4 ± 0.05	287.39 ± 3.47	4.00 ± 0.05
Lanzikui	411.03 ± 49.73	274.97 ± 95.51	44.02 ± 4.25	7.66 ± 0.11	0.71 ± 0.11	885.23 ± 2.76	3.77 ± 0.12	3.77 ± 0.12	3.77 ± 0.12	42.77 ± 3.03	3.77 ± 0.12
Jinpaohong	921.05 ± 24.1	524.45 ± 7.48	73.19 ± 0.53	106.84 ± 1.6	38.19 ± 0.48	1745.41 ± 39.11	120.81 ± 0.54	3.9 ± 0.04	4.8 ± 0.08	40.04 ± 0.83	3.88 ± 0.04
Weizi	1963.73 ± 20.9	3.61 ± 0.29	574.03 ± 27.04	106.88 ± 2.3	133.66 ± 6.66	25666.08 ± 1634.93	142.32 ± 2.1	1.86 ± 0.23	3.87 ± 0.13	786.97 ± 20.53	3.87 ± 0.13
Hongxia	732.93 ± 16.63	863.54 ± 8.03	39.8 ± 1.24	26.71 ± 1.92	22.78 ± 0.92	2136.81 ± 149.9	525.06 ± 20.18	3.92 ± 0.03	4.19 ± 0.42	148.69 ± 1.57	3.92 ± 0.03
Zangzihong	282.85 ± 8.68	211.49 ± 7.21	4.02 ± 0.01	987.42 ± 91.26	146.68 ± 2.68	1699.39 ± 20.16	439.21 ± 12.68	4.02 ± 0.01	4.02 ± 0.01	55.39 ± 1.52	4.02 ± 0.01
Wulongpengsheng	439.35 ± 8.59	23.06 ± 1.11	3.92 ± 0.15	227.88 ± 10.18	173.48 ± 6.3	664.52 ± 19.78	419.28 ± 28.71	3.97 ± 0.1	3.8 ± 0.54	96.05 ± 5.5	3.87 ± 0.07
Juanyehong	785.99 ± 12.06	59.64 ± 1.01	3.96 ± 0.01	770.33 ± 21.44	137.43 ± 2.29	1384.98 ± 33.62	564.33 ± 58.64	5.58 ± 0.14	3.91 ± 0.09	144.51 ± 0.98	3.94 ± 0.03
Shouanhong	1203.12 ± 82.6	50.33 ± 1.7	4.36 ± 0.44	3.94 ± 0.13	9.05 ± 0.28	3760.01 ± 307.62	391.1 ± 28.9	4.07 ± 0.06	4.07 ± 0.06	48.27 ± 1.21	4.07 ± 0.06
Hongbaoshi	748.12 ± 15.29	84.82 ± 4.45	64.93 ± 4.13	172.59 ± 5.35	57.06 ± 2.8	4388.88 ± 29.44	79.18 ± 5.85	5.43 ± 0.31	3.36 ± 0.53	336.96 ± 3.19	3.98 ± 0.04
Dahuhong	135.12 ± 15.9	3.97 ± 0.27	6.06 ± 0.2	4 ± 0.08	4.04 ± 0.12	738.08 ± 7.02	16.11 ± 0.81	4.1 ± 0.05	4.16 ± 0.08	77.15 ± 3.55	4.1 ± 0.05
Roufurong	240.79 ± 19.75	12.02 ± 0.45	5.36 ± 0.4	5.08 ± 0.32	3.88 ± 0.03	548.37 ± 19.81	33.94 ± 1.68	3.86 ± 0.01	3.96 ± 0.08	53.27 ± 2.18	3.88 ± 0.03
Shanhutai	389.04 ± 34.75	276.65 ± 98.7	45.56 ± 18.09	4.07 ± 14	4.27 ± 0.35	414.3 ± 194.63	8.62 ± 0.72	4.02 ± 0.2	4.2 ± 0.33	29.55 ± 8.83	4.02 ± 0.06
Xueyingtaohua	458.33 ± 9	78.19 ± 2.6	9.55 ± 0.18	31.79 ± 1.28	3.8 ± 0.22	828.96 ± 35.47	7.32 ± 0.2	4.41 ± 0.39	4.28 ± 0.34	47.42 ± 1.81	4.03 ± 0.06
Nihonghuancai	297.92 ± 12.16	65.86 ± 1.42	7.78 ± 0.21	356.54 ± 18.27	6.32 ± 0.11	470.07 ± 22.82	49.42 ± 0.56	3.94 ± 0.05	8.52 ± 0.38	355.74 ± 9	3.92 ± 0.03

Zhihong	1615.77 ± 1.99	4 ± 0.06	48.6 ± 0.77	4.04 ± 0.02	54.87 ± 0.8	3492.76 ± 37.67	126.56 ± 3.03	3.46 ± 0.24	3.67 ± 0.2	668.41 ± 6.99	4.0 ± 0.06
Shibahao	1676.9 ± 8.54	6.71 ± 0.42	30.73 ± 1.54	5.86 ± 0.25	12.36 ± 0.16	925.85 ± 19.61	20.62 ± 0.6	4.03 ± 0.03	3.47 ± 0.39	496.62 ± 4.32	4.03 ± 0.03
Yaohuang	1876.15 ± 58.31	34.32 ± 2.75	54.9 ± 3.6	102.53 ± 3.7	76.54 ± 0.58	2811.9 ± 253.09	216.11 ± 19.22	3.92 ± 0.04	3.92 ± 0.04	350.31 ± 8.88	3.92 ± 0.04
Xiangyu	238.28 ± 7.64	274.78 ± 9.61	63.59 ± 2.47	383.36 ± 3.74	25.32 ± 0.61	757.3 ± 15.56	72.59 ± 0.74	4.09 ± 0.06	5.75 ± 0.35	69 ± 1.37	4.09 ± 0.06
Jingyu	1077.21 ± 64.42	12.59 ± 0.58	111.35 ± 7.17	172.09 ± 2.12	116.75 ± 2.57	5354.67 ± 197.25	536.83 ± 22.99	4.15 ± 0.28	3.95 ± 0.04	291.57 ± 10.69	3.95 ± 0.04
Baixueta	820.92 ± 26	14.54 ± 0.37	93.53 ± 1.43	47.34 ± 1.17	67.95 ± 2.16	4037.58 ± 87.29	39.65 ± 2	15.7 ± 0.19	4.15 ± 0.13	330.18 ± 4.84	4.06 ± 0.07

1 **Table 4.** Macro and trace elements in different fresh peony flowers

Accession	Macro elements				Trace elements			
	Na	K	Ca	Mg	Fe	Mn	Cu	Zn
Morunjuelun	4.162 ± 0.0077	10.84 ± 1.6878	3.309 ± 0.0665	2.225 ± 1.116	1.133 ± 0.1377	0.018 ± 0.0003	0.008 ± 0.0003	0.163 ± 0.0307
Gejinzi	4.167 ± 0	12.353 ± 0.6577	3.894 ± 0.131	1.34 ± 0.2233	0.733 ± 0.0382	0.016 ± 0.0002	0.007 ± 0.0001	0.163 ± 0.0054
Linghuazhanlu	4.167 ± 0	15.145 ± 1.2184	3.134 ± 0.0162	1.7 ± 0.741	1.05 ± 0.075	0.019 ± 0.0002	0.008 ± 0.0003	0.168 ± 0.0194
Lanzikui	3.953 ± 0.0283	8.953 ± 0.892	4.725 ± 0.0731	1.166 ± 0.1287	0.317 ± 0.0289	0.009 ± 0.0004	0.003 ± 0.0002	0.053 ± 0.0054
Jinpaohong	0.882 ± 0.8121	28.562 ± 3.9065	3.024 ± 0.6219	4.932 ± 0.4364	0.267 ± 0.0289	0.002 ± 0.0007	0.002 ± 0.0003	0.004 ± 0.0007
Weizi	3.864 ± 0.0247	10.604 ± 0.4482	4.555 ± 0.0246	0.949 ± 0.4995	0.325 ± 0.0433	0.008 ± 0.0004	0.002 ± 0.0003	0.045 ± 0.0013
Hongxia	4.004 ± 0.0306	11.346 ± 1.0486	4.839 ± 0.057	2.082 ± 0.918	0.475 ± 0.2165	0.01 ± 0.0004	0.003 ± 0.0003	0.055 ± 0.0272
Zangzihong	4.167 ± 0	13.822 ± 0.6447	3.514 ± 0.0185	2.137 ± 2.7718	1.083 ± 0.101	0.019 ± 0.0001	0.009 ± 0.0005	0.182 ± 0.039
Wulongpengsheng	4.084 ± 0.0287	9.697 ± 1.1186	4.963 ± 0.105	1.571 ± 1.2141	0.567 ± 0.1607	0.012 ± 0.0003	0.004 ± 0.0005	0.092 ± 0.0322
Juanyehong	3.737 ± 0.0646	12.091 ± 1.2282	4.611 ± 0.1521	2.076 ± 0.4191	0.292 ± 0.0382	0.006 ± 0.0005	0.001 ± 0.0001	0.034 ± 0.0026
Shouanhong	4.004 ± 0.0077	11.346 ± 0.5779	4.839 ± 0.007	2.082 ± 0.1374	0.475 ± 0.0577	0.01 ± 0.0003	0.003 ± 0.0002	0.055 ± 0.0038
Hongbaoshi	4.107 ± 0.0042	13.523 ± 0.0279	4.153 ± 0.0665	2.692 ± 0.0045	0.908 ± 0.0382	0.015 ± 0.0002	0.005 ± 0.0001	0.095 ± 0.0036
Dahuhong	4.167 ± 0	13.218 ± 0.38	3.12 ± 0.0544	1.203 ± 0.2238	1.075 ± 0.025	0.02 ± 0.0001	0.009 ± 0.0001	0.195 ± 0.0031
Roufurong	4.164 ± 0.0048	15.373 ± 2.009	3.85 ± 0.0789	0.932 ± 0.1807	0.675 ± 0.05	0.015 ± 0.0002	0.006 ± 0.0002	0.145 ± 0.0044
Shanhutai	1.178 ± 0.1084	7.363 ± 0.0139	0.803 ± 0.2666	0.62 ± 0.0021	0.192 ± 0.0382	0.002 ± 0.0002	0.003 ± 0.0004	0.047 ± 0.0027
Xueyingtaohua	1.549 ± 1.1632	12.123 ± 1.1423	4.221 ± 0.3414	2.938 ± 3.1897	0.292 ± 0.1377	0.003 ± 0.0006	0.002 ± 0.0016	0.004 ± 0.0035
Nihonghuancai	4.109 ± 0.0184	12.128 ± 0.6534	4.669 ± 0.0915	1.695 ± 1.6081	0.542 ± 0.052	0.014 ± 0.0003	0.005 ± 0.0003	0.102 ± 0.0288

Zhihong	3.232 ± 0.2682	12.403 ± 0.7988	4.048 ± 0.0544	1.397 ± 0.2114	0.233 ± 0.0144	0.005 ± 0.0004	0.001 ± 0.0002	0.008 ± 0.0069
Shibahao	4.158 ± 0.0154	10.017 ± 0.4275	3.481 ± 0.0647	1.593 ± 0.8619	0.858 ± 0.1283	0.017 ± 0.0002	0.007 ± 0.0003	0.163 ± 0.0188
Yaohuang	4.116 ± 0.0051	6.988 ± 0.4949	4.676 ± 0.0242	1.517 ± 0.076	0.467 ± 0.0144	0.013 ± 0.0002	0.004 ± 0.0002	0.108 ± 0.0022
Xiangyu	4.136 ± 0.0125	18.073 ± 2.8463	4.48 ± 0.2145	2.302 ± 0.7093	0.608 ± 0.0289	0.014 ± 0.0002	0.005 ± 0.0002	0.124 ± 0.004
Jingyu	4.167 ± 0	10.305 ± 2.6011	3.827 ± 0.2709	3.134 ± 2.7157	0.925 ± 0.1521	0.018 ± 0.0002	0.007 ± 0.0005	0.16 ± 0.0405
Baixueta	4.167 ± 0	14.103 ± 0.9878	3.325 ± 0.0731	1.474 ± 0.2881	1.033 ± 0.0289	0.018 ± 0.0002	0.008 ± 0.0002	0.177 ± 0.0038