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Effects of Soil Physical and Chemical Properties on the Quality of Nanjing 'Yuhua' Tea, a Type of Famous Green Tea

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Abstract: Tea has become one of the most popular drinks worldwide because of its special taste and health benefits. 'Yuhua' tea is a famous specialty of Nanjing, China, a green tea produced from *Camelia sinensis*. It belongs to the green tea category and is one of the top ten most famous teas in China. The physical and chemical properties of soil are very important to the quality of tea. However, at present, there are few instances of research on the soil of the 'Yuhua' tea cultivation area. To provide the theoretical basis for improving the final quality of 'Yuhua' tea by soil management measures, the effects of the soil's physical and chemical properties on the contents of important chemical components (free amino acids, tea polyphenols, and caffeine) of 'Yuhua' tea in three different cultivation areas in Nanjing were studied. The quality of 'Yuhua' tea is greatly influenced by the physical and chemical properties of the soil in which the tea plant grows. The free amino acid content and tea polyphenol content of tea leaves were significantly and negatively correlated with soil bulk density, pH, and water-soluble calcium content, while a significantly positive correlation was noticed between the two criteria and soil effective nitrogen, phosphorus, and potassium content. Additionally, the growth of the tea tree will be hampered and perhaps stressed if the soil's helpful mineral concentration is too low. The tea tree may produce more caffeine as a result, which could lower the quality of the tea leaves. Therefore, implementing targeted soil management techniques is the key to promoting tea tree growth and improving tea quality. This study laid the foundation for the adoption of corresponding soil management measures to improve the quality of 'Yuhua' tea.

Keywords: soil physical properties; soil chemical properties; tea leaves quality; 'Yuhua' tea

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1. Introduction

Tea is one of the most popular beverages in the world, owing to its distinct flavor, taste, and health advantages [1,2]. In the past ten years, the area used to produce tea has expanded by nearly 66%, reaching 5.3 million tons on 3.5 million hectares of land across 50 tea-growing nations [3]. In addition to having a delicious, nuanced flavor and a rich cultural history, tea provides health benefits for preventing and treating several pathological conditions, including cancer, inflammation, cardiovascular disease, obesity, COVID-19, etc. [4–8].

The polyphenols, caffeine, and amino acids in fresh tea leaves are the three key elements that define the quality of tea, even if different processing techniques have an impact on the ultimate quality of commercial tea [9]. This is particularly true for green tea because it is an unfermented tea and its early preparation involves actions such as steaming or roasting to deactivate the oxidase activity, preventing any oxidation from happening during further processing steps [10]. The astringency of green tea is thought to be determined by polyphenols, whereas freshness and sweetness are provided by free amino acids and bitterness by caffeine [11,12]. The combination and harmony of these three chemicals establish the vital taste character, organoleptic quality, and monetary worth of green tea [13]. Additionally, green tea must generally have a phenol-to-ammonia ratio of no more than seven, and a low phenol-to-ammonia ratio can improve the quality of green tea [14].

The physical and chemical properties of the soil are essential factors affecting the yield and quality of the tea [15,16]. On the one hand, the tea tree's ability to absorb water and nutrients from the soil is directly influenced by the physical and chemical characteristics of the soil, and on the other hand, the essential plant elements in the soil are also closely related to the tea tree's secondary metabolism, which includes the biosynthesis of chemical substances that determine the tea's quality [17]. In addition, changes in soil properties resulting from severe erosion and declining fertility have disturbed many tea plantations, leading to falling output and quality [18]. And regrettably, the increase in the frequency of extreme weather events, such as heavy precipitation, that have been brought on by human activity and global climate change will give soil erosion a stronger push, and this tendency is anticipated to become more prominent in the future [19,20]. Unquestionably, this has raised the bar for managing tea gardens. Therefore, it is critical to investigate how soil characteristics affect tea quality and implement focused soil management strategies to preserve and enhance tea quality. In the current study, we investigated the relationship between soil characteristics and fresh tea quality in three 'Yuhua'tea production regions in Nanjing to establish a foundation for understanding this relationship and implementing appropriate soil management practices to enhance tea quality.

2. Material and Methods

2.1. Site Information and Experimental Design

On the 17th and 18th of April, 2021, research was carried out at three locations in Nanjing: Huanglongxian (118°41′46″ E, 31°47′10″ N), Zhongshanling (118°51′35″ E, 32°3′59″ N), and Pingshan (118°50′51″ E, 32°27′27″ N). A sunny area with a slope of 5–10° in the above three locations where tea is grown was selected as the study area. Further, the sampling area at each site was randomly divided into 3 blocks, with about the same amount of tea leaves collected from each block, and 9 soil samples were collected in an "S" pattern from each block, which were immediately mixed to represent the overall soil condition of the block. Additionally, soil samples were taken along the vertical projection of the edge of the tea tree where the tender leaves were harvested, and after appropriate removal of debris from the ground, the original soil was taken with a ring knife at 0–20 cm and 20–40 cm soil layers and brought back to the laboratory. A sufficient number of young leaves were collected according to the standard of one bud and one leaf and brought back to the laboratory in ice boxes.

2.2. Determination of Physical and Chemical Properties of Soil Samples

A portion of the soil sample was then dried at 105 °C, weighed, and its bulk density calculated. Meanwhile, the other soil samples were air-dried, ground, and sieved through a 2 mm sieve to determine the mechanical composition of the soil, pH, ammonium nitrogen, available phosphorus, and available potassium. The soil's mechanical composition was then determined by a specific gravity meter; the soil's pH was determined by the potentiometric method. Then the soil ammonium nitrogen was determined by the KCl leaching—Indophenol blue colorimetric method, the effective potassium by NH_4OAc leaching—flame photometric method, and the effective phosphorus was determined by ammonium fluoride-hydrochloric acid solution leaching—spectrophotometric method [21]. What is more, the determination of the relative proportions of powder, clay, and sand in the soil was made according to the criteria of Balasubramanian and Hallam (2017) [22] and then the method of Carpenter et al. (2007) [23] was used to determine the classification of the soil at different sites.

2.3. Determination of the Quality Index Content of Tea Leaves

After being brought back to the laboratory, the tender leaves collected were quickly placed in the oven and baked at 105 °C for 15 min, and then at 70 °C to a constant mass. Then, according to the following method, a sufficient quantity of dried tea samples was prepared. The free amino acid content was determined by ninhydrin chromogenic spectrophotometry [24], and the tea polyphenol content was determined by reference to GB/T 8313-2018 [25], while the caffeine content was determined by reference to GB/T 8312-2013 [26].

2.4. Statistics Analysis

Three replicates were used to set up each measurement, and the results were displayed as mean ± standard deviation. Using Excel 2010, the data processing was carried out. One-way analysis of variance (ANOVA) and Duncan's multiple comparisons were performed using SPSS 26.0, and differences between various treatment groups are indicated by different letters ($p < 0.05$) where they are significant.

3. Results

3.1. Soil Properties in Different Sites

As shown in Table 1, the three sites all have a high proportion of silty soil within the range of 0–20 and 20–40 cm. In terms of soil classification, the soils in the three study sites belong to silty soil. The soils at Pingshan had a significantly lower bulk density than at the other two sites for both 0–20 and 20–40 cm. The chemical properties of the soil at the three sites are shown in Table 2. The soil pH at all three sites was within the range (of four to six) suitable for tea tree growth [15]. Although the pH of the soil at Zhongshanling was significantly higher than that at the other two sites for both 0–20 and 20–40 cm. Moreover, for the effectiveness of macronutrients in the soil, ammonium N, available potassium, and available phosphorus were significantly higher in Pingshan soil than in the other two sites. Additionally, the water-soluble calcium content of the soil at Zhongshanling was significantly higher than that at the other sites.

Table 1. Soil physical properties in the three sampling sites.

Sites	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Soil Classification	Bulk Density (g cm^{-1})
Huanglongxian	0–20	2.70 ± 0.44 a	90.04 ± 0.86 ab	7.27 ± 1.16 ab	Silt	1.44 ± 0.12 a
	20–40	2.41 ± 0.18 a	88.11 ± 1.77 b	9.49 ± 1.86 a	Silt	1.53 ± 0.03 a
Zhongshanling	0–20	2.33 ± 0.66 a	87.86 ± 2.07 b	9.82 ± 2.35 a	Silt	1.52 ± 0.14 a
	20–40	3.24 ± 0.1 a	89.14 ± 0.88 b	7.62 ± 1.63 ab	Silt	1.56 ± 0.07 a
Pingshan	0–20	2.33 ± 0.51 a	91.47 ± 1.21 a	6.21 ± 1.5 b	Silt	1.06 ± 0.07 b
	20–40	2.08 ± 0.87 a	92.58 ± 1.27 a	5.34 ± 0.76 b	Silt	1 ± 0.14 b

The significant variations are shown by different letters at the 0.05 level.

Table 2. Soil chemical properties in the three sampling sites.

Sites	Depth (cm)	pH	AN	AP	AK	WSC
Huanglongxian	0–20	4.95 ± 0.56 ab	11.17 ± 2.41 b	11.67 ± 6.9 b	34.67 ± 11.27 b	120 ± 26.46 b
	20–40	5.17 ± 0.37 ab	17.27 ± 5.23 b	22.11 ± 2.22 b	39.07 ± 5.2 b	336.67 ± 176.16 b
Zhongshanling	0–20	5.54 ± 0.19 a	10.47 ± 2.57 b	20.37 ± 7.58 b	24.33 ± 11.75 b	916.67 ± 125.03 a
	20–40	5.65 ± 0.18 a	9.67 ± 1.55 b	24.58 ± 4.29 b	32.4 ± 7.14 b	916.67 ± 128.97 a
Pingshan	0–20	4.54 ± 0.09 b	72.63 ± 3.76 a	96.86 ± 25.42 a	123.47 ± 24.91 a	190 ± 20 b
	20–40	4.67 ± 0.27 b	79.67 ± 18.99 a	67.24 ± 4.72 a	179.63 ± 25.85 a	130 ± 34.64 b

AN: Ammonium nitrogen; AP: Available phosphorus; AK: Available potassium; WSC: Water-soluble calcium. The significant variations are shown by different letters at the 0.05 level.

3.2. The Content of Chemical Compositions in Tea Leaves

As shown in Figure 1, the free amino acid content of fresh tea from Pingshan was significantly higher than that of the other sites, 67% and 275% higher than that of Huanglongxian and Zhongshanling, respectively. What's more, the polyphenol content of fresh tea from Pingshan is also significantly higher than that of other locations, being 8% and 18% higher than that of Huanglongxian and Zhongshanling, respectively. The phenol-to-ammonia ratio of fresh tea at Zhongshanling is significantly higher than at other sites and far exceeds seven, the standard for green tea production. In terms of caffeine, Huanglongjian's fresh tea contains significantly more than the other two sites, 5% and 19% more than Zhongshanling and Pingshan, respectively.

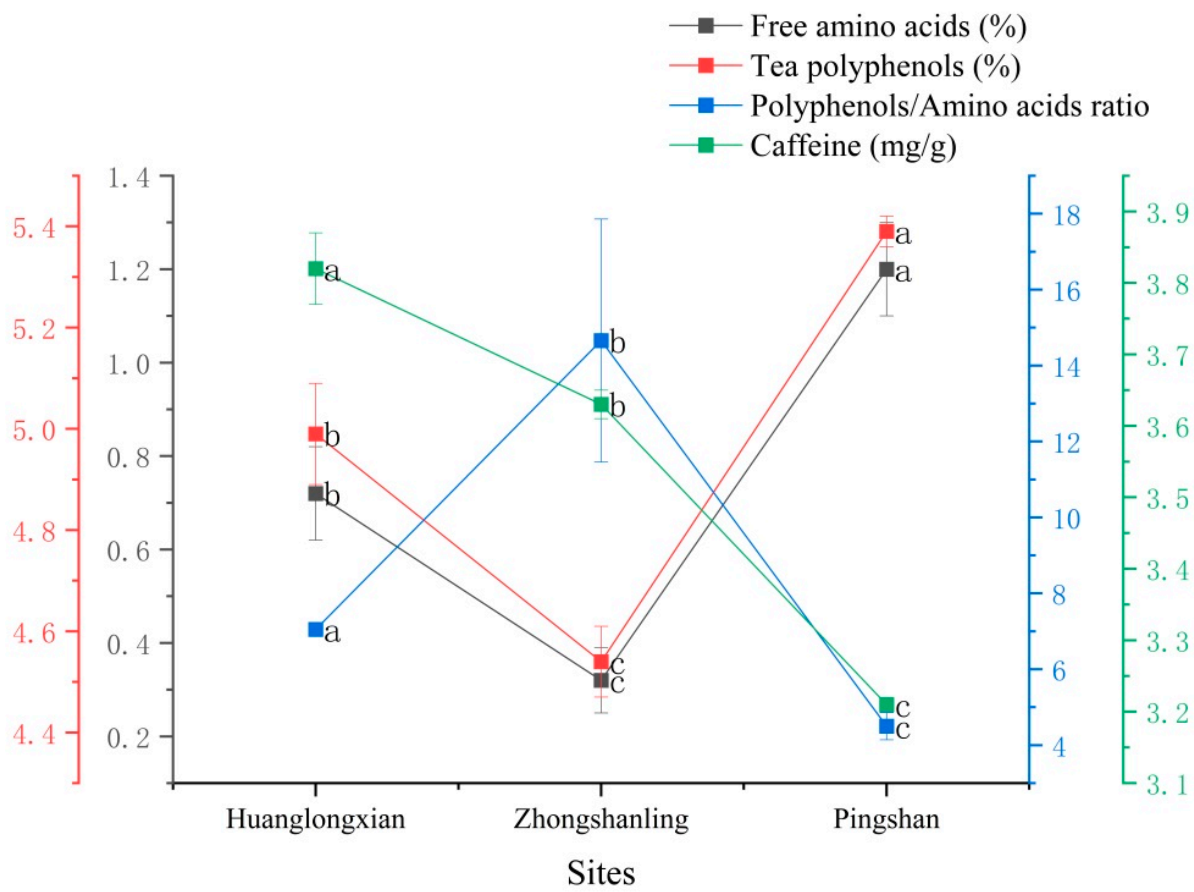

Figure 1. Chemical components in tea leaves in the three sampling sites. The significant variations are shown by different letters at the 0.05 level.

3.3. Relationship between Tea Leaves Compositions and Soil Properties

Overall, the correlation between each soil property and each tea-leaf chemical component was consistent at 0–20 cm and 20–40 cm soil depth across the three sites (Table 3). The free amino acid and tea polyphenol content of tea leaves were negatively correlated with soil bulk and pH, while a significantly positive correlation was observed between the criteria and the soil effective nitrogen, phosphorus, and potassium content (Table 3). Further, for the phenol-ammonia ratio and caffeine content of tea leaves, there is a significant positive correlation between soil bulk and the criteria, while ammonium nitrogen, available potassium, and available phosphorus were negatively correlated with the criteria (Table 3).

Table 3. Correlations of soil properties to the tea-leaves indicators in the three sampling sites.

Chemical Components	Soil Physical and Chemical Properties											
	Depth (0–20 cm)						Depth (20–40 cm)					
	BD	pH	AN	AP	AK	WSC	BD	pH	AN	AP	AK	WSC
Free amino acids	−0.838 **	−0.792 *	0.878 **	0.747 *	0.882 **	−0.76 *	−0.899 **	−0.874 **	0.844 **	0.84 **	0.874 **	−0.853 **
Tea polyphenols	−0.788 *	−0.736 *	0.839 **	0.738 *	0.84 **	−0.84 **	−0.814 **	−0.785 *	0.832 **	0.797 *	0.839 **	−0.933 **
Polyphenols/Amino acids ratio	0.675 *	0.799 *	−0.667 *	−0.562	−0.669 *	0.871 **	0.689 *	0.81 **	−0.685 *	−0.606	−0.649	0.862 **
Caffeine	0.826 **	0.519	−0.941 **	−0.921 **	−0.878 **	0.131	0.901 **	0.606	−0.874 **	−0.953 **	−0.92 **	0.446

Note: BD: Bulk density; AN: Ammonium nitrogen; AP: Available phosphorus; AK: Available potassium; WSC: Water-soluble calcium. Significance correlation levels: * $p < 0.05$; ** $p < 0.01$. Same below.

4. Discussion

4.1. Effect of Soil Physical Properties on the Quality of Tea Leaves

The soils at all three study sites were silty, suggesting good drainage, which may be beneficial to the growth of tea trees (Table 1). The lower bulk weight reflects higher soil porosity, which facilitates the growth and development of plant roots [27]. In general, however, this type of soil has a poor fertility retention capacity, so this hints at the importance of enhancing soil fertility in these sites. In this study, the soil bulk density was inversely proportional to the free amino acid and tea polyphenol contents in tea leaves and directly proportional to the phenol-ammonia ratio, which indicated that proper reduction of bulk density could improve the tea quality (Table 3). There are many outstanding studies that show that the addition of biochar can reduce the soil's bulk density [28–31]. Therefore, we can consider adding biochar to tea plant cultivation, especially when the soil bulk density is high. Previous studies have also shown that adding biochar can enhance the environmental friendliness of tea plantations by reducing greenhouse gas emissions from acidic soils in tea plantations, in addition to improving soil properties [32]. However, the amount of biochar added should be carefully considered because biochar is commonly alkaline [33], and too much of it is bound to be detrimental to the growth of tea trees.

Soil pH is considered to be the "master variable" of soil chemistry, which directly or indirectly influences the solubility of elements in the soil and determines their mobility and bioavailability [34]. Ma et al. (2017) [35] showed that soil pH was negatively correlated with amino acids, tea polyphenols, and theanine in tea. In this study, the soil pH was inversely proportional to the free amino acid and tea polyphenol contents in tea leaves and directly proportional to the phenol-ammonia ratio, which indicated that proper reduction of the pH value could improve the tea quality. However, it is inadvisable to lower the soil pH below four, as that would be outside the fitness range of the tea tree [15]. Although the study by Ruan et al. (2007) [36] presented different results, it showed that when the soil pH is less than four, the growth of young tea tree shoots is inhibited to a greater extent than nitrogen uptake, leading to an eventual increase in the total amount of free amino acids in tea leaves at the expense of tea yield due to the accumulation effect.

The effect of pH on tea quality may be achieved by influencing the availability of nutrients in the soil. So we correlated pH with the content of macronutrients in the soil (Table 4). Soil pH was inversely proportional to the AN, AP, and AK in tea leaves and directly proportional to the WSC. The same result was also obtained by Khadka et al. (2016) [37]. To further explore the relationship between pH and nutrient elements, we conducted regression analyses of pH and each nutrient element. Overall, the results obtained by linear regression are consistent with those obtained by Pearson correlation analysis (Supplementary Figures S1–S4). In addition, this suggested that pH accounted for about 45%, 40%, 46%, and 53% of the total variability in AN, AP, AK, and WSC, respectively. The research results of Wen et al. (2020) [38] also showed that soil pH value was significantly negatively correlated with available nitrogen (ammonium nitrogen plus nitrate nitrogen), which could provide some evidence for the results of this study. In fact, tea plants, which are suitable for acidic soils, prefer to absorb ammonium nitrogen when absorbing nitrogen from the soil [39]. Furthermore, one possible explanation for the negative correlation between pH and AP is that when the content of soluble calcium in the soil is high, as the pH value increases, Ca precipitates P from the solution, especially when the pH value is less than seven [34]. This is consistent with the fact that pH was positively correlated with water-soluble calcium content and negatively correlated with effective phosphorus content in this study.

4.2. Effect of Soil Macronutrients on the Quality of Tea Leaves

Nitrogen, phosphorus, and potassium are macronutrients essential for plant growth and development. Many studies have shown that the application of nitrogen, phosphorus, and potassium fertilizers can improve the tea's quality [40–45]. In addition, although the total nitrogen, phosphorus, and potassium content of the soil may be high, the amount of effective nitrogen, phosphorus, and potassium available for direct plant uptake is generally inadequate, especially in some regions (including East Asia) [46,47]. The quality of the tea leaves at all three sites in this study was not high, as evidenced by the low free amino acid content (the generally normal value is 1–3%) and the relatively large phenol-to-ammonia ratio (around 7 for Huanglongjian tea leaves and a much greater 7 for Zhongshanling tea leaves) (Figure 1). This may be due to the low AN, AP, and AK in the soils of all three study sites, with Huanglongjian and Zhongshanling being particularly low (Table 2). Despite differences in climatic conditions and tea plant varieties, it is generally accepted that the minimum AK concentration required for tea plantation soils is 80 mg/kg [48]. It can be seen that the concentration of AK in the soil was significantly lower than this value at all three sites in this study, except for Pingshan. What is more, the results of this study showed that the AN, AP, and AK contents in soil were positively correlated with free amino acids and tea polyphenols in tea leaves, but negatively correlated with the phenol-ammonia ratio (Table 3). This suggests that increasing the AN, AP, and AK content in the soil can improve the tea's quality. At the same time, due to its acidic soils combined with the relatively adequate rainfall in most tea-producing areas, the risk of loss of nitrogen, phosphorus, and potassium leaching from tea plantations is high [43,49]. Therefore, nitrogen, phosphorus, and potassium fertilizers should be applied in the appropriate periods and doses to improve the tea's quality. At the same time, attention should be paid to the amount and balance of chemical fertilizers applied or the switch to organic fertilizers should be made in order to avoid excessive soil acidification, environmental pollution, and a decline in tea quality [14,49–52].

Table 4. Correlations of soil pH value to macronutrients in the three sampling sites.

Soil Depth (cm)		AN	AP	AK	WSC
0–20	pH	−0.658	−0.609	−0.681 *	0.685 *
20–40		−0.734 *	−0.728 *	−0.797 *	0.777 *

Significance correlation levels: * $p < 0.05$.

4.3. The Special Effects of Caffeine

Caffeine, as an alkaloid, has been shown to have the ability to enhance plant resistance to biotic and abiotic stresses such as bacterial, fungal, insect, and chromium stresses by inducing the salicylic acid pathway in plants [53–56]. In this study, the caffeine content of tea leaves was negatively and significantly correlated with the AN, AP, and AK contents of the soil (Table 3). This may be because the nutrients in the soil, such as AN, AP, and AK, are not able to support the good growth and development of the tea trees, possibly due to poor management in these three tea-growing locations, and may even put the tea trees under stress from adversity. One possible piece of evidence to support the above hypothesis is that caffeine content has a significant positive correlation with soil bulk density (Table 3). This perhaps indicates that the increase in soil bulk density is detrimental to the growth and development of tea trees. Similar studies have previously shown that caffeine levels in tea increase when the quality of the tea leaves is reduced due to nutrient deficiencies in the soil [57].

5. Conclusions

The quality of 'Yuhua' tea, a variety of green tea, is greatly influenced by the physicochemical characteristics of the soil in which the tea plant is grown. Properly lowering the soil bulk density and pH value and increasing the effective nitrogen, phosphorus, and potassium content can effectively improve the quality of 'Yuhua' tea by increasing the free amino acid content of tea leaves and tea polyphenol content and reducing the phenol-ammonia ratio of tea leaves. And when the amount of useful minerals in the soil is insufficient, the tea tree's growth is hampered, and it may even become stressed. This can cause the tea tree to produce more caffeine, which lowers the quality of the tea leaves.

Therefore, it is crucial to implement targeted soil management techniques to promote the growth of tea plants and improve the quality of tea leaves.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae9020189/s1, Figure S1: The relationship between AN and pH in the three sampling sites; Figure S2: The relationship between AP and pH in the three sampling sites; Figure S3: The relationship between AK and pH in the three sampling sites; Figure S4: The relationship between WSC and pH in the three sampling sites.

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References

1. Khan, N.; Mukhtar, H. Tea Polyphenols in Promotion of Human Health. *Nutrients* **2018**, *11*, 39. [CrossRef] [PubMed]
2. Xianchen, Z.; Huiguang, J.; Xiaochun, W.; Yeyun, L. The effects of different types of mulch on soil properties and tea production and quality. *J. Sci. Food Agric.* **2020**, *100*, 5292–5300. [CrossRef] [PubMed]
3. Wei, C.; Yang, H.; Wang, S.; Zhao, J.; Liu, C.; Gao, L.; Xia, E.; Lu, Y.; Tai, Y.; She, G.; et al. Draft genome sequence of *Camellia sinensis* var. sinensis provides insights into the evolution of the tea genome and tea quality. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 4151–4158.
4. Yan, Z.; Zhong, Y.; Duan, Y.; Chen, Q.; Li, F. Antioxidant mechanism of tea polyphenols and its impact on health benefits. *Anim. Nutr.* **2020**, *6*, 115–123. [CrossRef] [PubMed]
5. Wang, S.; Moustaid-Moussa, N.; Chen, L.; Mo, H.; Shastri, A.; Su, R.; Bapat, P.; Kwun, I.; Shen, C.-L. Novel insights of dietary polyphenols and obesity. *J. Nutr. Biochem.* **2014**, *25*, 1–18. [CrossRef]
6. Yang, C.S.; Zhang, J.; Zhang, L.; Huang, J.; Wang, Y. Mechanisms of body weight reduction and metabolic syndrome alleviation by tea. *Mol. Nutr. Food Res.* **2016**, *60*, 160–174. [CrossRef]
7. Mhatre, S.; Srivastava, T.; Naik, S.; Patravale, V. Antiviral activity of green tea and black tea polyphenols in prophylaxis and treatment of COVID-19: A review. *Phytomedicine* **2021**, *85*, 153286. [CrossRef]
8. Henss, L.; Auste, A.; Schürmann, C.; Schmidt, C.; von Rhein, C.; Mühlebach, M.D.; Schnierle, B.S. The green tea catechin epigallocatechin gallate inhibits SARS-CoV-2 infection. *J. Gen. Virol.* **2021**, *102*, 001574. [CrossRef]
9. Wen, B.; Ren, S.; Zhang, Y.; Duan, Y.; Shen, J.; Zhu, X.; Wang, Y.; Ma, Y.; Zou, Z.; Fang, W. Effects of geographic locations and topographical factors on secondary metabolites distribution in green tea at a regional scale. *Food Control* **2020**, *110*, 106979. [CrossRef]
10. Xing, L.; Zhang, H.; Qi, R.; Tsao, R.; Mine, Y. Recent Advances in the Understanding of the Health Benefits and Molecular Mechanisms Associated with Green Tea Polyphenols. *J. Agric. Food Chem.* **2019**, *67*, 1029–1043. [CrossRef]
11. Zhang, L.; Cao, Q.-Q.; Granato, D.; Xu, Y.-Q.; Ho, C.-T. Association between chemistry and taste of tea: A review. *Trends Food Sci. Technol.* **2020**, *101*, 139–149. [CrossRef]
12. Yang, Y.; Kim, J.; Chung, J.-O.; Cho, D.; Roh, J.-H.; Hong, Y.-D.; Kim, W.-G.; Kang, H. Variations in the composition of tea leaves and soil microbial community. *Biol. Fertil. Soils* **2022**, *58*, 167–179. [CrossRef]
13. Krahe, J.C.; Krahe, M.A.; Roach, P.D. Development of an objective measure of quality and commercial value of Japanese-styled green tea (*Camellia* L. sinensis): The Quality Index Tool. *J. Food Sci. Technol.* **2018**, *55*, 2926–2934.
14. Xie, S.; Feng, H.; Yang, F.; Zhao, Z.; Hu, X.; Wei, C.; Liang, T.; Li, H.; Geng, Y. Does dual reduction in chemical fertilizer and pesticides improve nutrient loss and tea yield and quality? A pilot study in a green tea garden in Shaoxing, Zhejiang Province, China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 2464–2476. [CrossRef]
15. Fu, H.; Li, H.; Yin, P.; Mei, H.; Li, J.; Zhou, P.; Wang, Y.; Ma, Q.; Jeyaraj, A.; Thangaraj, K.; et al. Integrated Application of Rapeseed Cake and Green Manure Enhances Soil Nutrients and Microbial Communities in Tea Garden Soil. *Sustainability* **2021**, *13*, 2967. [CrossRef]

16. Yang, G.; Zhou, D.; Wan, R.; Wang, C.; Xie, J.; Ma, C.; Li, Y. HPLC and high-throughput sequencing revealed higher tea-leaves quality, soil fertility and microbial community diversity in ancient tea plantations: Compared with modern tea plantations. *BMC Plant Biol.* **2022**, *22*, 239. [CrossRef] [PubMed]
17. Tseng, W.-Y.; Lai, H.-Y. Comprehensive Analysis Revealed the Specific Soil Properties and Foliar Elements Respond to the Quality Composition Levels of Tea (*Camellia sinensis* L.). *Agronomy* **2022**, *12*, 670. [CrossRef]
18. Liu, S.; Yang, R.; Peng, X.; Hou, C.; Ma, J.; Guo, J. Contributions of Plant Litter Decomposition to Soil Nutrients in Ecological Tea Gardens. *Agriculture* **2022**, *12*, 957. [CrossRef]
19. Xu, Q.-X.; Wu, P.; Dai, J.-F.; Wang, T.-W.; Li, Z.-X.; Cai, C.-F.; Shi, Z.-H. The effects of rainfall regimes and terracing on runoff and erosion in the Three Gorges area, China. *Environ. Sci. Pollut. Res.* **2018**, *25*, 9474–9484. [CrossRef]
20. Duan, J.; Liu, Y.-J.; Yang, J.; Tang, C.-J.; Shi, Z.-H. Role of groundcover management in controlling soil erosion under extreme rainfall in citrus orchards of southern China. *J. Hydrol.* **2020**, *582*, 124290. [CrossRef]
21. Bao, S.D. *Analysis of Soil Agro-Chemistry*, 3rd ed.; China Agriculture Press: Beijing, China, 2000. (In Chinese)
22. Balasubramanian, A. Soil Taxonomy and Classification. (Issue April). 2017. Available online: https://www.researchgate.net/publication/315785518_SOIL_TAXONOMY_CLASSIFICATION?channel=doi&linkId=58e4b4faa6fdccc85bdf4176&showFulltext=true (accessed on 23 November 2022). [CrossRef]
23. Carpenter, D.D.; Hallam, L. *An Investigation of Rain Garden Planting Mixtures and the Implications for Design*; Southeast Oakland County Water Authority: Royal Oak, MI, USA, 2007.
24. Moore, S.; Stein, W.H. Photometric nin-hydrin method for use in the ehromatography of amino acids. *J. Biol. Chem.* **1948**, *176*, 367–388. [CrossRef] [PubMed]
25. All China Federation of Supply and Marketing Cooperatives. *GBT8313-2008 Determination of Total Polyphenols and Catechins Content in Tea*; China Standards Press: Beijing, China, 2018.
26. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China. *GBT8312-2013 Tea-Determination of Caffeine Content. Method Using High-Performance Liquid Chromatography*; China Standards Press: Beijing, China, 2014.
27. Mao, Q.; Hu, B.; Agathokleous, E.; Wang, L.; Koike, T.; Ma, M.; Rennenberg, H. Biochar application improves karstic lime soil physicochemical properties and enzymes activity and enhances sweet tea seedlings physiological performance. *Sci. Total Environ.* **2022**, *830*, 154815. [CrossRef] [PubMed]
28. Al-Wabel, M.I.; Usman, A.R.; El-Naggar, A.H.; Aly, A.A.; Ibrahim, H.M.; Elmaghraby, S.; Al-Omran, A. Conocarpus biochar as a soil amendment for reducing heavy metal availability and uptake by maize plants. *Saudi J. Biol. Sci.* **2015**, *22*, 503–511. [CrossRef] [PubMed]
29. Blanco-Canqui, H. Biochar and Soil Physical Properties. *Soil Sci. Soc. Am. J.* **2017**, *81*, 687–711. [CrossRef]
30. Xiu, L.; Zhang, W.; Sun, Y.; Wu, D.; Meng, J.; Chen, W. Effects of biochar and straw returning on the key cultivation limitations of Albic soil and soybean growth over 2 years. *Catena* **2019**, *173*, 481–493. [CrossRef]
31. Toková, L.; Igaz, D.; Horák, J.; Aydin, E. Effect of Biochar Application and Re-Application on Soil Bulk Density, Porosity, Saturated Hydraulic Conductivity, Water Content and Soil Water Availability in a Silty Loam Haplic Luvisol. *Agronomy* **2020**, *10*, 1005. [CrossRef]
32. Wang, H.; Yi, H.; Zhang, X.; Su, W.; Li, X.; Zhang, Y.; Gao, X. Biochar Mitigates Greenhouse Gas Emissions from an Acidic Tea Soil. *Pol. J. Environ. Stud.* **2020**, *29*, 323–330. [CrossRef]
33. Yuan, J.H.; Xu, R.K.; Zhang, H. The forms of alkalis in the biochar produced from crop residues at different temperatures. *Bioresour. Technol.* **2011**, *102*, 3488–3497. [CrossRef]
34. Penn, C.J.; Camberato, J.J. A critical review on soil chemical processes that control how soil pH affects phosphorus availability to plants. *Agriculture* **2019**, *9*, 120. [CrossRef]
35. Ma, Y.-H.; Fu, S.-L.; Zhang, X.-P.; Zhao, K.; Chen, H.Y. Intercropping improves soil nutrient availability, soil enzyme activity and tea quantity and quality. *Appl. Soil Ecol.* **2017**, *119*, 171–178. [CrossRef]
36. Ruan, J.; Gerendás, J.; Härdter, R.; Sattelmacher, B. Effect of root zone pH and form and concentration of nitrogen on accumulation of quality-related components in green tea. *J. Sci. Food Agric.* **2007**, *87*, 1505–1516. [CrossRef]
37. Khadka, D.; Lamichhane, S.; Thapa, B. Assessment of relationship between soil pH and macronutrients, western Nepal. *J. Chem. Biol. Phys. Sci. JCBPS* **2016**, *6*, 303.
38. Wen, B.; Zhang, X.; Ren, S.; Duan, Y.; Zhang, Y.; Zhu, X.; Wang, Y.; Ma, Y.; Fang, W. Characteristics of soil nutrients, heavy metals and tea quality in different intercropping patterns. *Agrofor. Syst.* **2020**, *94*, 963–974. [CrossRef]
39. Wang, R.; Chen, L.; Chen, J.; Chen, Y.; Zhang, Z.; Wang, X.; Peng, Y.; Peng, S.; Li, A.; Wei, X. Different nitrate and ammonium ratios affect growth and physiological characteristics of Ca-mellia oleifera Abel. seedlings. *Forests* **2018**, *9*, 784. [CrossRef]
40. Venkatesan, S.; Murugesan, S.; Ganapathy, M.N.; Verma, D.P. Long-term impact of nitrogen and potassium fertilizers on yield, soil nutrients and biochemical parameters of tea. *J. Sci. Food Agric.* **2004**, *84*, 1939–1944. [CrossRef]
41. Mudau, F.N.; Soundy, P.; Du Toit, E.S. Effects of nitrogen, phosphorus, and potassium nutrition on total polyphenol content of bush tea (*Athrixia phylicoides* L.) leaves in shaded nursery environment. *HortScience* **2007**, *42*, 334–338. [CrossRef]
42. Lin, Z.H.; Chen, L.S.; Chen, R.B.; Zhang, F.Z. Antioxidant system of tea (*Camellia sinensis*) leaves in response to phosphorus supply. *Acta Physiol. Plant* **2012**, *34*, 2443–2448. [CrossRef]

43. Ruan, J.; Ma, L.; Shi, Y. Potassium management in tea plantations: Its uptake by field plants, status in soils, and efficacy on yields and quality of teas in China. *J. Plant Nutr. Soil Sci.* **2013**, *176*, 450–459. [CrossRef]
44. Liu, M.Y.; Burgos, A.; Ma, L.; Zhang, Q.; Tang, D.; Ruan, J. Lipidomics analysis unravels the effect of nitrogen fertilization on lipid metabolism in tea plant (*Camellia sinensis* L.). *BMC Plant Biol.* **2017**, *17*, 165. [CrossRef]
45. Ma, L.; Yang, X.; Shi, Y.; Yi, X.; Ji, L.; Cheng, Y.; Ni, K.; Ruan, J. Response of tea yield, quality and soil bacterial characteristics to long-term nitrogen fertilization in an eleven-year field experiment. *Appl. Soil Ecol.* **2021**, *166*, 103976. [CrossRef]
46. Nkebiwe, P.M.; Weinmann, M.; Bar-Tal, A. Fertilizer placement to improve crop nutrient acquisition and yield: A review and meta-analysis. *Field Crops Res.* **2016**, *196*, 389–401. [CrossRef]
47. Wang, Y.; Chen, Y.; Wu, W. Potassium and phosphorus transport and signaling in plants. *J. Integr. Plant Biol.* **2020**, *63*, 34–52. [CrossRef] [PubMed]
48. Huang, W.; Lin, M.; Liao, J.; Li, A.; Tsewang, W.; Chen, X.; Sun, B.; Liu, S.; Zheng, P. Effects of Potassium Deficiency on the Growth of Tea (*Camelia sinensis*) and Strategies for Optimizing Potassium Levels in Soil: A Critical Review. *Horticulturae* **2022**, *8*, 660. [CrossRef]
49. Yan, P.; Shen, C.; Fan, L.; Li, X.; Zhang, L.; Zhang, L.; Han, W. Tea planting affects soil acidification and nitrogen and phosphorus distribution in soil. *Agric. Ecosyst. Environ.* **2018**, *254*, 20–25. [CrossRef]
50. Yang, X.-D.; Ni, K.; Shi, Y.-Z.; Yi, X.-Y.; Zhang, Q.-F.; Fang, L.; Ma, L.-F.; Ruan, J. Effects of long-term nitrogen application on soil acidification and solution chemistry of a tea plantation in China. *Agric. Ecosyst. Environ.* **2018**, *252*, 74–82. [CrossRef]
51. Wang, Z.; Geng, Y.; Liang, T. Optimization of reduced chemical fertilizer use in tea gardens based on the assessment of related environmental and economic benefits. *Sci. Total Environ.* **2020**, *713*, 136439. [CrossRef] [PubMed]
52. Tang, S.; Pan, W.; Tang, R.; Ma, Q.; Zhou, J.; Zheng, N.; Wang, J.; Sun, T.; Wu, L. Effects of balanced and unbalanced fertilisation on tea quality, yield, and soil bacterial community. *Appl. Soil Ecol.* **2022**, *175*, 104442. [CrossRef]
53. Kim, Y.S.; Lim, S.; Yoda, H.; Choi, Y.E.; Sano, H. Simultaneous activation of salicylate production and fungal resistance in transgenic chrysanthemum producing caffeine. *Plant Signal. Behav.* **2011**, *6*, 409–412. [CrossRef]
54. Wang, Y.C.; Qian, W.J.; Li, N.N.; Hao, X.Y.; Wang, L.; Xiao, B.; Wang, X.C.; Yang, Y.J. Metabolic changes of caffeine in tea plant (*Camellia sinensis* (L.) *O. Kuntze*) as defense response to *Colletotrichum fructicola*. *J. Agric. Food Chem.* **2016**, *64*, 6685–6693. [CrossRef]
55. Emanuil, N.; Akram, M.S.; Ali, S.; Majrashi, A.; Iqbal, M.; El-Esawi, M.A.; Ditta, A.; Alharby, H.F. Exogenous Caffeine (1,3,7-Trimethylxanthine) Application Diminishes Cadmium Toxicity by Modulating Physio-Biochemical Attributes and Improving the Growth of Spinach (*Spinacia oleracea* L.). *Sustainability* **2022**, *14*, 2806. [CrossRef]
56. Park, J.C.; Yoo, Y.; Lim, H.; Yun, S.; Win, K.T.; Kim, K.M.; Lee, G.S.; Cho, M.H.; Lee, T.H.; Sano, H.; et al. Intracellular Ca^{2+} accumulation triggered by caffeine provokes resistance against a broad range of biotic stress in rice. *Plant Cell Environ.* **2022**, *45*, 1049–1064. [CrossRef] [PubMed]
57. Jahan, I.; Shopan, J.; Rahman, M.; Sarkar, A.; Baset, A.; Zhang, Z.; Li, X.; Ahammed, G.J.; Hasan, K. Long-Term Traditional Fertilization Alters Tea Garden Soil Properties and Tea Leaf Quality in Bangladesh. *Agronomy* **2022**, *12*, 2128. [CrossRef]