Flower morphology attributes of fruit yield of tea (Camellia sinensis L.)

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Research Article

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Abstract

Background: This study investigated the relationship between the flower morphology and fruit yield of tea plants. Tea plants have late self-incompatibility, and cross-pollination can improve fruit yield. However, fruit yield considerably differs among tea varieties. Other factors might affect pollination and fruit yield. This study analyzed 106 tea varieties to determine the relationship between flower morphology and fruit yield.

Results: The average fruit yield per plant of the tea varieties exhibited a positively skewed distribution. The higher the yield was, the lower was the proportion of the varieties. According to the relative position between the anther and stigma, the tea varieties were divided into the stigma and anther superior groups. Multiple relationships were observed between floral morphology and fruit yield. The stigma superior group accounted for approximately 85% of the population, and fruit yield was significantly higher in the stigma superior group than in the anther superior group. The longer the pistil was than the stamen, the higher the fruit yield was. The effect of the style width on fruit yield was opposite between the groups. In the stigma superior group, the wider the style width was, the higher was the fruit yield. By contrast, in the anther superior group, the wider the style width was, the lower was the fruit yield.

Conclusion: Flower morphology affects the fruit yield of tea plants. In tea breeding, the stigma being higher than the anther is conducive for harvesting fruit. Moreover, the increase in the style width is beneficial for increasing fruit yield and might help pollinating insects in contacting the stigma.

Background

Tea is among the most widely consumed beverages globally and is a vital cash crop in Taiwan. Different varieties of tea plants have been grown in Taiwan for more than 200 years (Chiu 1988; Jun and Lin 1997). In Taiwan, the tea cultivation area has reached 12,266 hectares, and 14,341 metric tons of tea is produced every year (Council of Agriculture 2021). Tea tree is a perennial outcrossing woody plant (Barua 1963). Taiwan has high tea genetic resources and diversity (Taniguchi et al. 2014). Many studies have extensively focused on the detection of tea genetic resources in Taiwan (Hu 2004; Hu et al. 2005, 2006, 2011; Sanui 2011; Shyu and Juan 1993; Tsai 2003).

Oil is extracted from tea seeds in many parts of the world, and tea seed oil is mainly composed of unsaturated fatty acids, mainly oleic acid, and other fatty acids in small proportions (George et al. 2016). Tea seed oil may be a potential source of natural antioxidants (George et al. 2013, 2015). Tea seeds have different sizes (Altuntas and Yildiz 2017). The oil content of tea seeds ranges from 16% to 25% (Barooah et al. 2020; Houng et al. 2016; George et al. 2013). Ten types of fatty acids were detected in tea seed oil, and five and six types of fatty acids were identified in oil extracted from *Camellia oleifera* and *Camellia tenuifolia* seeds, respectively (Houng et al. 2016).

Tea plants exhibit late-acting self-incompatibility (LSI), including plants from the genus *Camellia* (*C. oleifera*) (Liao et al. 2014). (Chen et al. 2012; Kumarihami et al. 2016; Yang 1998; Yang and Chen 2000; Zhang et al. 2016). Because of LSI, the pollen tubes of self-pollinated plants fail to fertilize and experience difficulty in entering the ovule (Chen et al. 2012). LSI hinders the pollen tube, which is present at the base of the style, ovary, or ovule (Yang 1998; Yang and Chen 2000). Transcriptome analysis of the style after selfing and outcrossing indicated that the LSI of tea plants may be controlled by gametophyte genes (Zhang et al. 2016).

Fluorescence microscopy revealed the blockage of the pollen tube of self-pollinated tea plants; however, successful fertilization occurred in these plants 48 hours after pollination (Seth et al. 2019). Tea pollen viability was positively correlated with temperature; pollen germination was not affected by rainfall and humidity (Muoki et al. 2010). In the pistil of tea plants, the content of potassium is the highest, followed by those of calcium, magnesium, and phosphorus. The calcium content increased after self-pollination and decreased after cross-pollination, whereas the potassium content decreased after self-pollination and increased after cross-pollination. Calcium and potassium are crucial for self-incompatibility in tea plants (Ma et al. 2018).

Tea plants remain in the vegetative stage because of commercial picking. However, the regulation of climate change, hybrid improvement, flowering, and fruiting must be studied (Piyasundara et al. 2018). A study examined the morphological distribution of the floral organs of core tea species, including the degree of style protrusion (Taniguchi et al. 2014). Changes in floral morphology, especially the morphological characteristics of the style, result in gradient changes in phenotypic characteristics instead of obvious changes. The fruit contains two seeds on average and matures 8–9 months after pollination. More than 1 month and 4 months are required for the development of the zygote and embryo of tea plants, respectively (Ariyarathna et al. 2011). In tea plants, the success rate of artificial hybridization ranges from 4.6% to 26% (Ariyarathna et al. 2011; Kottawa-Arachchi et al. 2019). In different tea genotypes, anthers may be at the same, higher, or lower position than the stigma position (Ariyarathna et al. 2007, 2011). In some almond varieties, the effect of style length on pollen tube growth and stigma versus the anther position indicated the possibility of natural selfing (Kodad and Socias i Company 2005).

Many types of insects visit and pollinate flowers in tea gardens (Mitra et al. 2018). In southern China, wild bees and flies aid in the pollination of *Camellia* plants. The activity of visiting insects peaks between 10:00 and 14:00. In a previous study, insect cross-pollination significantly improved the fruit yield of three *Camellia* species, namely *C. osmantha*, *C. vietnamensis*, and *C. oleifera* (Wei et al. 2019).

The yield of tea fruits directly affects the yield of seeds, and the yield of tea varieties varies considerably. The findings of this study indicated that flower morphology may affect the chance of pollen contacting the stigma after an insect visit, thus affecting the yield of tea fruits.

Methods

Plant materials

This study investigated 106 tea varieties (Fig. 1) originally planted in the garden (at an altitude, longitude, and latitude of 200 m, 24.909, and 121.186, respectively) established by the Tea Research and Extension Station in 1994 for preserving tea varieties. Each variety was planted in a row of 20 plants, with a spacing of 50 and 180 cm between plants and rows, respectively; the plants were planted following the same tea tree cultivation method. The branches were pruned to the same height in late January 2012 to ensure the normal growth of plants and fruit. Subsequently, the branches were pruned in mid-December after the fruits were harvested in late October 2013. The branches were not pruned again until the fruits were harvested in winter 2015. Twenty plants of each variety were harvested in late October 2013 and 2015 to calculate the fruit yield per plant.

[Insert Figure 1 here]

Flower morphology

From November 2019, a total of 10 fresh and fully open flowers of each variety of tea were collected every morning. After the collection, the characteristics of tea flowers were determined indoors using a cursor ruler, including the length of the pistil (the highest point), length of the stamen (the highest point), inner and outer widths of the stamen bundle, and width of the style. We included the varieties whose length of the pistil was shorter than that of the stamen in the anther superior group and those whose length of the pistil was longer than or equal to that of the stamen in the stigma superior group (Table 1). Figure 1 presents the morphological diagram of the floral apparatus of the tea plants used in this study.

[Insert Table 1 here]

Evaluation for the homogeneity of phenotypic traits within species

The homogeneity of phenotypic traits within the varieties was evaluated by calculating the intraclass correlation coefficient (ICC). The interpretation of the ICC was based on the guideline reported by Koo and Li (2016): ICC values of <0.5, 0.5–0.75, 0.75–0.9, and >0.9 indicate poor, moderate, good, and excellent homogeneity, respectively.

Table 1 presents the homogeneity of phenotypic traits within the varieties based on ICC values. The ICCs of all the 106 varieties were >0.9, indicating the presence of excellent homogeneity in each set of 10 flowers within the 106 varieties of *C. sinensis*. Thus, the averaged phenotypic traits were directly used in subsequent statistical analyses.

Statistical analysis

Continuous data, including yield and phenotypic traits, are presented as median and interquartile range (IQR). Yield and phenotypic traits between the two groups of "pistil length shorter than stamen length" and "pistil length longer than stamen length" were compared using the nonparametric Mann–Whitney test. Correlations between yield and phenotypic traits were evaluated by determining Spearman's correlation coefficient (Spearman's ρ, a nonparametric measure of rank correlation): 0.8 ≤ Spearman's ρ < 1 indicates a strong monotonic correlation, 0.4 ≤ Spearman's ρ < 0.8 indicates a moderate monotonic correlation, and 0 ≤ Spearman's ρ < 0.4 indicates a weak monotonic correlation. General linear models were used to determine the effects of phenotypic traits on yield. The corresponding weight coefficients with 95% confidence intervals are summarized and tabulated. A two-sided P value of <0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics 25.0 (IBM Corporation, Armonk, New York).

Results

Yield distribution of test tea varieties within 2 years

The average fruit yield per plant of a tea variety exhibited a positively skewed distribution (Fig. 2). The findings indicated that the higher the yield was, the lower was the proportion of varieties. The yields of 0–200, 201–400, 401–600, and 601–800 kg accounted for 83%, 9%, 5%, and only 3% of the total varieties, respectively, in 2013 and 52.2%, 21.8%, 15.7%, and 7.58% of the total varieties, respectively, in 2015. The yields of 801–1000, 1001–1200, and >1200 kg were observed only for one plant. Because of the annual change in tea fruit yield, the average fruit yield in 2 years was used as the benchmark for determining the corresponding flower characteristics in this study.

[Insert Figure 2 here]

Distribution of fruit yield between the anther and stigma superior groups

A total of 106 tea varieties with 20 individual plants for each variety were examined in this study. These individual plants had a median yield of 135.0 (IQR: 44.6–269.5) g. Among the 106 varieties, the average length of the pistil of 16 (15.1%) varieties was shorter than that of the stamen, with a median difference of −0.3 mm. These 16 varieties were included in the anther superior group. The remaining 90 (84.9%) varieties with a median difference of 1.0 mm between the length of the pistil and that of the stamen were included in the stigma superior group (Fig. 1). The yield of the anther superior group was significantly lower than that of the stigma superior group, with the median value of 73.6 (IQR: 27.9–145.3) versus 157.8 g (IQR: 57.3–292.3; P = 0.02; Fig. 3).

[Insert Figure 3 here]

The results showed that the fruit yield of the anther superior group was significantly lower than that of the stigma superior group. Due to the self-incompatibility of tea, it is speculated that in the varieties with a higher anther, the stigmas may have less opportunities to contact cross pollens, resulting in the decline of fruit yield.

Differences in phenotypic traits between groups

The stamen length of the anther superior group was comparable to that the stigma superior group (median value: 10.7 vs. 10.9 mm). Furthermore, the pistil length and stigma width of the anther superior group were significantly shorter and lower than those of the stigma superior group, respectively (median value: 10.1 vs. 12.2 mm and 3.0 vs. 4.0 mm, respectively; $P < 0.001$). In addition, the anther superior group had a significantly lower stigma width minus stamen bundle inner width than did the stigma superior group (median values: 0.6 vs. 1.4 mm; $P = 0.023$; Table 2).

[Insert Table 2 here]

Monotonic correlations between phenotypic traits and yield

As presented in Table 3, yield was significantly negatively correlated with the stamen length, stamen bundle outer width, and stamen bundle outer width minus stamen bundle inner width (Spearman's $\rho = -0.196$, -0.243, and -0.254 and $P = 0.044$, 0.012, and 0.008, respectively). The strength of all the correlation coefficients was weak (absolute value of Spearman's $P < 0.4$). In addition, yield was significantly positively correlated with the stigma width minus stamen bundle inner width, with a weak correlation coefficient (Spearman's $\rho = 0.202$, $P = 0.038$).

[Insert Table 3 here]

Similar results were observed in the stigma superior group. Yield was weakly negatively correlated with the stamen length, stamen bundle outer width, and stamen bundle outer width minus stamen bundle inner width (Spearman's $\rho = -0.228$, -0.303, and -0.301 and $P = 0.031$, 0.004, and 0.004, respectively). Furthermore, a weak positive correlation was observed between yield and stigma width minus stamen bundle inner width (Spearman's $\rho = 0.216$, $P = 0.041$). In the anther superior group, yield was moderately negatively correlated with the stigma width minus stamen bundle inner width (Spearman's $\rho = -0.556$, $P = 0.025$).

Effects of phenotypic traits on yield

General linear models were used to investigate the effects of phenotypic traits on yield, and the results are presented in Table 4. The five variables of phenotypic traits significantly affected the yield of the individual plants of the 106 tea varieties. First, yield increased with a 1-mm increase in pistil length minus stamen length, with a weight coefficient of 35.3 g ($P = 0.037$), and no such correlation was observed in both the anther and stigma superior groups. Second, yield decreased with a 1-mm increase in the stamen bundle outer width, with a weight coefficient of −15.3 g ($P = 0.018$). A similar result was observed in the stigma superior group, with a weight coefficient of −19.4 g ($P = 0.006$). Third, yield decreased with a 1-mm increase in stamen bundle outer width minus stamen bundle inner width, with a weight coefficient of −20.3 g ($P = 0.008$). A similar result was observed in the stigma superior group, with a weight coefficient of −25.0 g ($P = 0.003$). In addition, yield increased with a 1-mm increase in stigma width minus stamen bundle inner width, with a weight coefficient of 22.8 g ($P = 0.039$). A contrasting result was observed in the anther superior group, in which yield decreased with a 1-mm increase in stigma width minus stamen bundle inner width, with a weight coefficient of −67.1 g ($P = 0.013$). Finally, yield significantly increased in the stigma superior group compared with the anther superior group, with an estimated difference of 102.5 g ($P = 0.023$).

[Insert Table 4 here]

Figure 4 presents the relationship between the lengths of the pistil and stamen and the width of the style minus the inner width of the stamen bundle and the fruit yield of the tea varieties, as determined using regression analysis. When the pistil was longer than the stamen, the fruit yield of the tea varieties was higher (Fig. 4a). When the pistil was longer and the width of the style minus the inner width of the stamen bundle was greater, the fruit yield of the tea varieties was higher. These findings may be related to the fact that the stigma easily comes into contact with the pollen carried by visiting insects (Fig. 4b). When the anther is in the upper position and the width of the style minus the width of the stamen bundle is higher, the stigma and anther are more likely to contact each other, reducing the possibility of the stigma contacting cross pollens and thus decreasing the yield of fruits in tea plants (Fig. 4c).

[Insert Figure 4 here]

Discussion

Because of the self-incompatibility of tea plants, the difference between the lengths of the pistils and stamens affects the fruit yield. When the pistil is shorter than the stamen, fruit yield is lower. In addition, when the pistil is longer, fruit yield is higher, and the style width is positively correlated with yield. The style width may affect the contact area of insect pollination. Although the correlation between the style width and yield is weak, the style width significantly affects yield.

The tendency to undergo selfing itself may be a driver of speciation, and this speculation should be investigated in future studies on diversity and speciation (Wright et al. 2013). Studies examining the relative position of the stamen and pistil of tea plants and breeding have mostly used the self-incompatible almond as the reference crop. The fruit yield of almond (*Prunus amygdalus*) varieties considerably differs after self-pollination, and this difference may be caused by partial self-incompatibility (MartÍNez-GarcÍA et al. 2011). In almond breeding, self-compatible germplasms are mainly screened. The relative position of the stigma and anthers indicates the possibility of natural selfing in some almond varieties. Pollinators would not be required in the natural selfing of a single variety of plant (Bernad and Socias i Company 1995). Most tea plants are self-incompatible. Self-incompatibility is the key to prevent inbreeding decline and maintain genetic diversity. A study used SSR markers to confirm selfing and indicated that the variety "Ziyan" is self-compatible (Tan et al. 2019). Some tea varieties exhibited a self-pollination rate of up to 20% (Wachira and Kamunya 2005). Therefore, tea varieties with self-compatibility should be explored in the future to facilitate tea tree breeding for preparing tea seed oil.

Conclusion

Tea fruit yield is a crucial index of oil extraction capacity. This study investigated the effect of flower traits on tea yield by determining the yield of 106 tea varieties in different years and by examining the characteristics of reproduction-related flower organs. The yield of the whole tea varieties exhibited a positively skewed distribution. Because tea plants are self-incompatible, increasing the chance of the stigma contacting cross pollens may increase the possibility of successful pollination. In this study, the varieties with flower pistils longer than the stamens accounted for 84.9% of the population. The average fruit yield of a single tree in this group was 84.2 g higher than that of the group with shorter pistils. Tea flowers with longer pistils might easily contact cross pollens. In the varieties with pistils longer than the stamens, the larger the style width was, the higher was the overall yield; this finding might be related to the larger contact area for cross flower pollens carried by insects, such as bees. The study findings provide a useful reference for tea breeders to select flower characteristics for oil production.

Abbreviations

LSI
Late-acting self-incompatibility.
ICC
Intraclass correlation coefficient.
IQR
Interquartile range.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The plant materials were provided by Tea Research and Extension Station, Council of Agriculture, Executive Yuan (TRES).

Competing interests

The authors declare that they have no conflict of interest.

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Authors' contributions

SKL, IZC and SFR designed the study; SKL and CYH performed experiments; SKL wrote the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1 Intraclass correlation coefficient (ICC) of flowers and the anther versus stigma position of the tea varieties

No.	Tea varieties	ICC of flowers	Anther vs stigma position
1	Chun-Ho-Sheng	0.992	Anther superior
2	Han-Kou	0.996	Anther superior
3	Hsiao-Tsu-Keng	0.992	Anther superior
4	Lin-Kou-Ta-Yeh-Wu	0.998	Anther superior
5	Manipuri	0.997	Anther superior
6	Niu-Pu	0.996	Anther superior
7	Pai-Mao-Hou	0.995	Anther superior
8	Shan-Cha	0.992	Anther superior
9	Shen-Man-Chung	0.993	Anther superior
10	Sou-Pei	0.996	Anther superior
11	Ssu-Chi-Chun	0.993	Anther superior
12	Ta-Hu-Wei	0.998	Anther superior
13	TTES No.4	0.992	Anther superior
14	TTES No.5	0.990	Anther superior
15	TTES No.8	0.993	Anther superior
16	Yu-Chih	0.995	Anther superior
17	Hei-Mien-Tsao-Chung	0.996	Stigma superior
18	Pu-Chih-Chun	0.993	Stigma superior
19	Tao-Jen-Chung	0.993	Stigma superior
20	Assam indigenous	0.995	Stigma superior
21	Chih-Lan	0.989	Stigma superior
22	Chi-Lan	0.986	Stigma superior
23	Chi-Lung-Chin-Kuei	0.994	Stigma superior
24	Chi-Lung-Pai-Chung	0.989	Stigma superior
25	Chi-Men	0.991	Stigma superior
26	Ching-Hsin-Ta-Mou	0.996	Stigma superior
27	Ching-Hsin-Tsao-Chung	0.992	Stigma superior
28	Ching-Hsin-Wu-Lung	0.996	Stigma superior
29	Chin-Kuei	0.991	Stigma superior
30	Chu-Yeh	0.997	Stigma superior
31	Feng-Lin-Tsai	0.995	Stigma superior
32	Fu-Chou	0.996	Stigma superior
33	Han-Hsiao	0.994	Stigma superior
34	Hei-Mao-Hou	0.989	Stigma superior
35	Heng-Che-Ta-Yeh	0.992	Stigma superior
36	Hsiao-Yeh-Tieh-Kuan-Yin	0.994	Stigma superior
37	Huang-Chih	0.994	Stigma superior
38	Huang-Chin-Kuei	0.987	Stigma superior
39	Huang-Hsin-Wu-Lung	0.995	Stigma superior
40	Huang-Kan	0.990	Stigma superior
41	Hu-Nan	0.978	Stigma superior
42	Hung-Hsin-Ta-Mou	0.994	Stigma superior
43	Hung-Hsin-Wu-Lung	0.993	Stigma superior

44	Hung-Hsin-Wu-Yi	0.997	Stigma superior
45	Hung-Wei-Tsai	0.993	Stigma superior
46	Jaipuri	0.993	Stigma superior
47	Jou-Kuei	0.989	Stigma superior
48	Kan-Tsai	0.993	Stigma superior
49	Kan-Tsai (Yellow)	0.995	Stigma superior
50	Kuei-Hua	0.994	Stigma superior
51	Kyang	0.998	Stigma superior
52	Mao-Hsieh	0.995	Stigma superior
53	Mao-Tsai	0.991	Stigma superior
54	Mei-Chan	0.990	Stigma superior
55	Mien-Tien	0.994	Stigma superior
56	Niu-Shih-Wu	0.990	Stigma superior
57	Pa-Hsien	0.995	Stigma superior
58	Pai-Hsin-Wu-Lung	0.996	Stigma superior
59	Pai-Hsin-Wu-Yi	0.995	Stigma superior
60	Pai-Yeh	0.986	Stigma superior
61	Ping-Shui	0.993	Stigma superior
62	Po-Yeh	0.989	Stigma superior
63	San-Cha-Chih-Lan	0.996	Stigma superior
64	Shan	0.996	Stigma superior
65	Shih-Cha	0.987	Stigma superior
66	Shui-Hsien	0.995	Stigma superior
67	Ssu-Chi-Chun-Pien-Chung	0.995	Stigma superior
68	Ta-Chi-Ling	0.993	Stigma superior
69	Ta-Ching-Tsao-Sheng	0.993	Stigma superior
70	Ta-Mou	0.995	Stigma superior
71	Ta-Nan-Wan-Hei-Mao-Hou	0.986	Stigma superior
72	Tan-Shui-Ching-Hsin	0.993	Stigma superior
73	Ta-Teng	0.996	Stigma superior
74	Ta-Yeh-Wu-Lung	0.995	Stigma superior
75	Tieh-Kuan-Yin	0.995	Stigma superior
76	Tien-Kung	0.992	Stigma superior
77	Tsao-Chung	0.996	Stigma superior
78	TTES No.1	0.990	Stigma superior
79	TTES No.10	0.992	Stigma superior
80	TTES No.11	0.991	Stigma superior
81	TTES No.12	0.989	Stigma superior
82	TTES No.13	0.993	Stigma superior
83	TTES No.14	0.989	Stigma superior
84	TTES No.15	0.996	Stigma superior
85	TTES No.16	0.996	Stigma superior
86	TTES No.17	0.988	Stigma superior
87	TTES No.19	0.997	Stigma superior

88	TTES No.2	0.996	Stigma superior
89	TTES No.20	0.991	Stigma superior
90	TTES No.21	0.990	Stigma superior
91	TTES No.3	0.995	Stigma superior
92	TTES No.6	0.991	Stigma superior
93	TTES No.7	0.991	Stigma superior
94	TTES No.9	0.987	Stigma superior
95	Tu-Tsai-Keng-Pai-Mao-Hou	0.995	Stigma superior
96	Tzu-Chung	0.995	Stigma superior
97	Wan-Chung	0.991	Stigma superior
98	Wen-Shan-Chih-Lan	0.992	Stigma superior
99	Wen-Shan-Ta-Yeh-Wu	0.995	Stigma superior
100	Wu-Chin	0.994	Stigma superior
101	Wu-Ku-Tsai	0.963	Stigma superior
102	Wu-Yi	0.995	Stigma superior
103	Wu-Yi-Pien-Chung (Yellow leaves)	0.990	Stigma superior
104	Yen-Chuan	0.993	Stigma superior
105	Ying-Chih-Hung-Hsin	0.992	Stigma superior
106	Ying-Chih-Tsao-Chung	0.990	Stigma superior

Table 2 Comparisons of phenotypic traits between the anther and stigma superior groups

Phenotypic trait	Total (N = 106)	Anther superior (pistil length < stamen length) (N = 16)	Stigma superior (pistil length ≥ stamen length) (N = 90)	P value
Pistil length (mm)	11.8 (10.3, 13.3)	10.1 (9.5, 10.9)	12.2 (11.0, 13.5)	<0.001*
Stamen length (mm)	10.9 (10.1, 11.9)	10.7 (10.1, 11.5)	10.9 (10.1, 12.0)	0.308
Pistil length minus stamen length (mm)	0.7 (0.2, 1.5)	−0.3 (−0.7, −0.1)	1.0 (0.4, 1.5)	<0.001*
Stamen bundle inner width (mm)	2.5 (2.1, 3.1)	2.4 (1.8, 2.6)	2.5 (2.2, 3.2)	0.073
Stamen bundle outer width (mm)	15.0 (14.0, 17.0)	14.6 (13.3, 15.6)	15.1 (14.0, 17.1)	0.123
Stamen bundle outer width minus stamen bundle inner width	12.4 (14.2, 11.5)	12.3 (13.5, 11.0)	12.5 (14.3, 11.5)	0.215
Stigma width (mm)	3.7 (2.9, 4.9)	3.0 (2.3, 3.5)	4.0 (3.0, 5.2)	<0.001*
Stigma width minus stamen bundle inner width (mm)	1.2 (0.2, 2.3)	0.6 (0.2, 1.2)	1.4 (0.5, 2.6)	0.023*

Data are presented as median and IQR

* $p < 0.05$ indicates that the difference between groups is statistically significant

Table 3 Correlations of yield versus phenotypic traits by group in tea varieties

Phenotypic traits		Total (N = 106)	Anther superior (pistil length < stamen length) (N = 16)	Stigma superior (pistil length ≥ stamen length) (N = 90)
Pistil length	Spearman's ρ	−0.054	−0.135	−0.167
	P value	0.584	0.617	0.117
Stamen length	Spearman's ρ	−0.196	−0.200	−0.228
	P value	0.044*	0.458	0.031*
Pistil length minus stamen length	Spearman's ρ	0.189	0.147	0.075
	P value	0.053	0.587	0.485
Stamen bundle inner width	Spearman's ρ	−0.058	0.138	−0.121
	P value	0.555	0.610	0.256
Stamen bundle outer width	Spearman's ρ	−0.243	−0.138	−0.303
	P value	0.012*	0.610	0.004*
Stamen bundle outer width minus stamen bundle inner width	Spearman's ρ	−0.254	−0.129	−0.301
	P value	0.008*	0.633	0.004*
Stigma width	Spearman's ρ	0.170	−0.432	0.156
	P value	0.081	0.094	0.141
Stigma width minus stamen bundle inner width	Spearman's ρ	0.202	−0.556	0.216
	P value	0.038*	0.025*	0.041*

* $p < 0.05$ indicates that the difference between groups is statistically significant

The correlation coefficients are presented as Spearman's ρ, a nonparametric measure of rank correlation

Table 4 Effects of phenotypic traits on the yield of tea varieties by group

Phenotypic trait	Total (N = 106)		Anther superior (pistil length < stamen length) (N = 16)		Stigma superior (pistil length ≥ stamen length) (N = 90)	
	Weight coefficient (95% CI)	P value	Weight coefficient (95% CI)	P value	Weight coefficient (95% CI)	P value
Pistil length	−2.1 (−19.4, 15.1)	0.807	−14.8 (−60.5, 30.9)	0.498	−11.2 (−31.1, 8.6)	0.264
Stamen length	−19.6 (−42.0, 2.8)	0.085	−13.8 (−59.6, 31.9)	0.527	−23.3 (−47.5, 0.9)	0.059
Pistil length minus stamen length	35.3 (2.2, 68.4)	0.037*	−4.4 (−104.1, 95.3)	0.926	20.4 (−24.3, 65.2)	0.367
Stamen bundle inner width	−11.8 (−54.2, 30.7)	0.584	8.6 (−82.8, 99.9)	0.843	−22.6 (−68.8, 23.7)	0.335
Stamen bundle outer width	−15.3 (−27.9, −2.7)	0.018*	−5.1 (−32.1, 21.9)	0.692	−19.4 (−33.0, −5.9)	0.006*
Stamen bundle outer width minus Stamen bundle inner width	−20.3 (−35.3, −5.4)	0.008*	−6.3 (−34.2, 21.6)	0.636	−25.0 (−41.2, −8.8)	0.003*
Stigma width	21.1 (−1.5, 43.7)	0.067	−44.1 (−90.7, 2.6)	0.062	17.8 (−7.8, 43.4)	0.171
Stigma width minus Stamen bundle inner width	22.8 (1.1, 44.5)	0.039*	−67.1 (−117.5, −16.6)	0.013*	21.4 (−2.3, 45.0)	0.076
Subgroup: Anther superior compared to stigma superior	102.5 (14.5, 190.5)	0.023*	–		–	

* $p < 0.05$ indicates a significant effect on yield

Figures

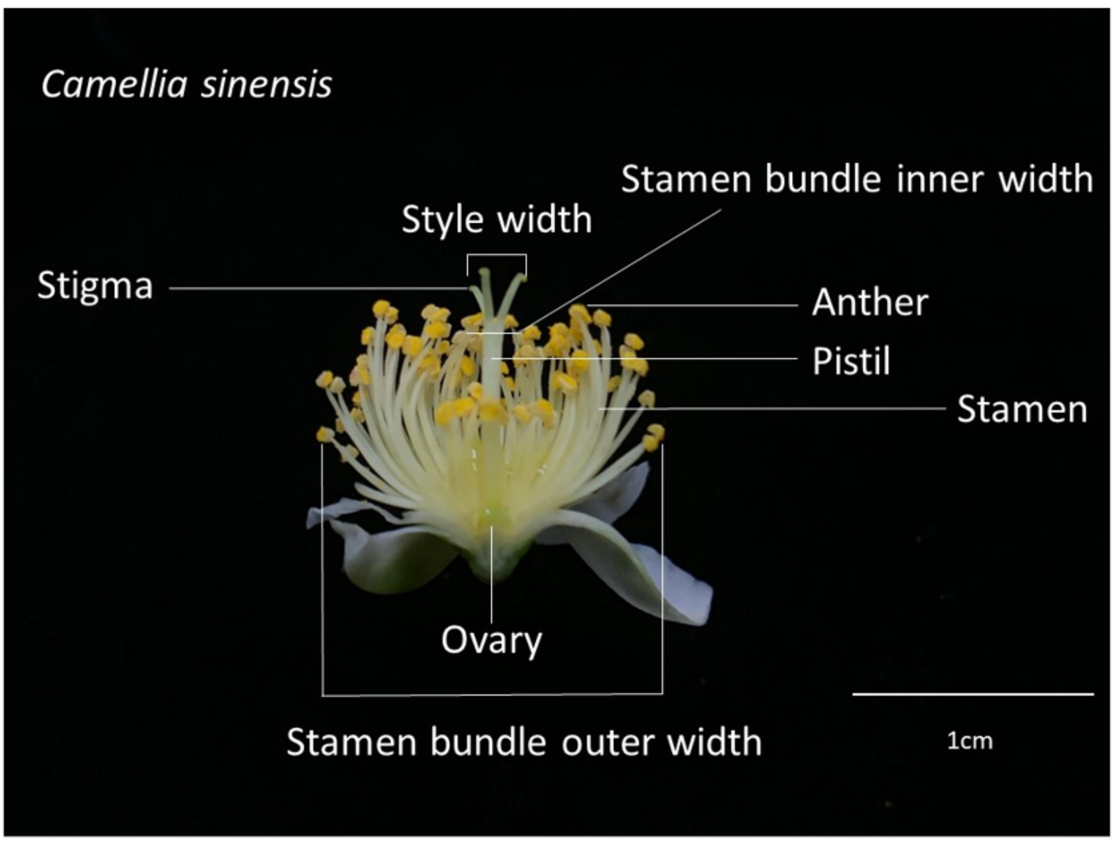

Figure 1

Morphological diagram of the tea floral apparatus

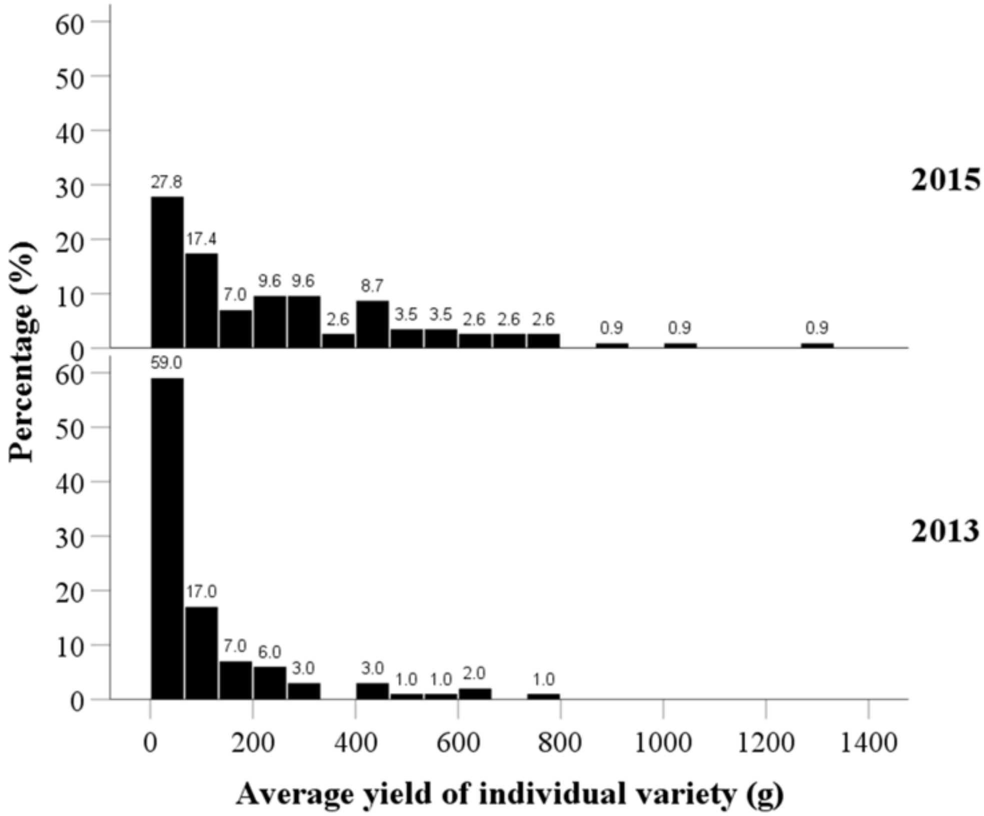

Figure 2

Distribution of the average fruit yield per plant of tea varieties in 2013 and 2015

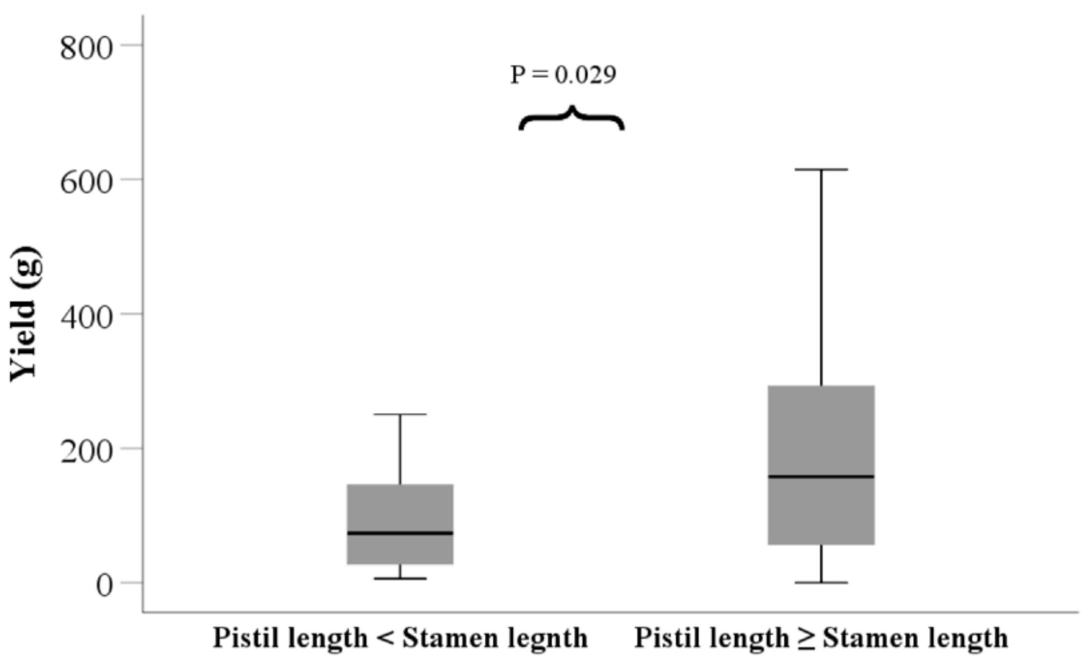

Figure 3

Distribution of fruit yield between the anther and stigma superior groups of the tea varieties

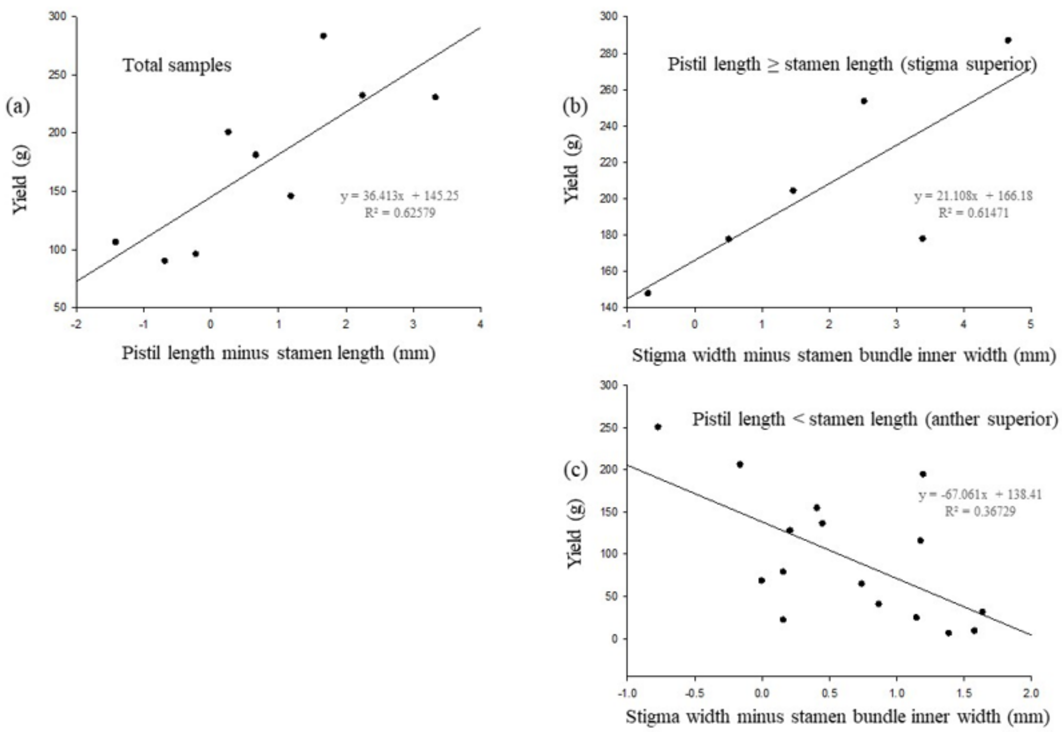

Figure 4

Effect of the relationship between pistil and stamen characteristics among tea varieties on fruit yield