

# Comparison and Evaluation of Fruit Traits of *Camellia oleifera* ‘Changlin’ in Jiangxi Province China

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**Keywords.** *Camellia oleifera*, comprehensive evaluation, fruit traits, regional performance

**Abstract.** Oil camellia (*Camellia oleifera*) is an oil-bearing crop. Jiangxi Province is the second-largest oil camellia-producing region in China. The agronomic performance of the cultivars was evaluated across different regions in Jiangxi Province. Ten areas were selected, and the fruit morphology, weight, moisture content, and primary economic traits of five ‘Changlin’ oil camellia cultivars were analyzed. Cultivar differences and regional variations in fruit characteristics were observed. CL53 had the greatest fruit size, fruit weight, moisture content in the pericarp and fresh seeds, weight of 100 fresh seeds, and weight of 100 dry seeds. The ratios of seed kernel to fruit weight, ranked from highest to lowest, were as follows: CL53, 35.10%; CL3, 33.28%; CL18, 30.95%; CL4, 30.17%; and CL40, 28.38%. The ratios of dry kernel weight to fresh fruit were as follows: CL18, 16.32%; CL53, 13.37%; CL3, 13.18%; CL40, 12.23%; and CL4, 10.25%. A principal component analysis showed that all five cultivars exhibited superior overall performance in specific region. The ranking of the comprehensive evaluation of fruit characters for each cultivar was as follows: CL53, CL4, CL40, CL18, and CL3. The ranking of the comprehensive evaluation of fruit characters for each location was as follows: PY, YX, YS, YD, WA, ZX, XF, SY, DX, and JS. In some regions, CL18 and CL3 are recommended as alternative cultivars. The regional adaptability and performance of ‘Changlin’ can inform optimal cultivar selection and planting arrangements in Jiangxi Province.

Oil camellia (*Theaceae Camellia* L.) is a valuable oil-bearing species (Chen et al. 2015). The oil extracted from oil camellia

seeds is rich in unsaturated fatty acids, which meets human nutritional needs (Wang et al. 2017) and offers potential cardiovascular health benefits (Chou et al. 2018). Oil camellia primarily thrives in hilly and mountainous areas, and production capacity is expected to reach 2 million tons by 2025 in China (Xu et al. 2023). The development of the oil camellia industry in China is crucial for rural revitalization, boosting farmers’ incomes, and addressing the imbalance in edible oil supply and demand (Chang et al. 2023).

Jiangxi Province is a central camellia oil-producing region in China, with a planting area of approximately 25,140 ha and a production capacity exceeding 200,000 tons in 2023 (Zhong 2024). Since the 1990s, the type and configuration of ‘Changlin’ series oil camellia cultivars have been continuously optimized,

resulting in the current configuration of five main cultivars, the utilization rate has exceeded 90% in Jiangxi Province. The performance of yields and fruit traits differ among cultivars across different areas (He et al. 2024; Yu et al. 2022; Zeng et al. 2024).

Oil camellia fruit yield serves as the primary evaluation index. However, factors such as planting methods, plant age, and alternating fruit-bearing cycles substantially influence yield, leading to marked variation in fresh fruit yield per plant across different cultivars. Fruit traits can be used to systematically compare and evaluate the performance of cultivars across different regions (Zhu et al. 2024).

The high and stable yield performance and fruit traits of each ‘Changlin’ series oil camellia cultivar have been fully demonstrated. To optimize the cultivar composition of ‘Changlin’ oil camellia cultivars across Jiangxi Province, a comprehensive evaluation of their regional performance is essential. However, existing studies have not yet comprehensively covered all areas of Jiangxi Province or the five Changlin series cultivars.

This study systematically compared and evaluated the fruit traits of five Changlin oil camellia cultivars across 10 regions in Jiangxi Province, thereby providing valuable references for their selection and optimal configuration in various cultivation areas throughout Jiangxi.

## Methods

### Sampling site

Based on the regional distribution of the oil camellia industry in Jiangxi Province, 10 representative regions were selected for fruit sample collection. These regions include Yongxiu County in northern Jiangxi, Poyang County and Dexing City in northeastern Jiangxi, Yushui District in western Jiangxi, Zixi County, Jishui and Wan’an Counties in central Jiangxi, and Shangyu, Yudu, and Xinfeng Counties in southern Jiangxi (Table 1).

### Sample collection and measurement

From 18–25 Oct 2023, fruit samples of the following five cultivars were collected from each sampling site: Changlin 53 (CL53); Changlin 40 (CL40); Changlin 18 (CL18); Changlin 4 (CL4); and Changlin 3 (CL3).

The investigation indices of fruit traits included morphology (fruit height, narrow diameter, wide diameter, narrow/wide diameter, shape index), weight (single fruit, pericarp, seeds, seed coat, and seed kernel weights), moisture content [pericarp moisture content (PMC), seed moisture content (SMC), seed coat moisture content (SCMC), seed kernel moisture content (SKMC)], and key economic traits including weight of 100 fresh seeds (100-FSW), weight of 100 dry seeds (100-DSW), ratio of dry seed weight to fresh fruit weight (DS/FF), ratio of dry kernel weight to dry seed weight (DK/DS), and ratio of dry kernel weight to fresh fruit weight (DK/FF).

Accepted for publication 6 Oct 2025.

Published online 5 Nov 2025.

This research was funded by the CAF Fundamental Research Funds (CAFYBB2023ZA001-2), the Key R&D Program “Unveiling and Leading” Projects of Jiangxi Province (20223BBF61012), the Natural Science Foundation of Jiangxi Province (20242BAB20302), and the Oil Camellia Special Research Project of Jiangxi Provincial Department of Forestry [JXYCZX(2023)010201].

The authors declare no competing interests.

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Table 1. Basic information about sampling sites.

| Regions              | Specific location                    | Longitude and latitude            | Soil type       | Altitude | Annual avg precipitation | Annual avg air temp |
|----------------------|--------------------------------------|-----------------------------------|-----------------|----------|--------------------------|---------------------|
| Yongxiu County (YX)  | Chaxi village, Yunshan township      | E 114°40'57.91"<br>N 29°03'54.80" | Red soil        | 50 m     | 1486 mm                  | 17.4 °C             |
| Poyang County (PY)   | Youcheng township                    | E 116°54'58.69"<br>N 29°10'40.25" | Red soil        | 100 m    | 1500 mm                  | 17.6 °C             |
| Dexing (DX)          | Jietian village, Zhangcun township   | E 117°34'53.61"<br>N 28°51'12.39" | Yellow-red soil | 100 m    | 1853 mm                  | 17.2 °C             |
| Yushui District (YS) | Liangang village, Mahong township    | E 115°02'05.22"<br>N 27°58'32.21" | Yellow-red soil | 100 m    | 1550 mm                  | 17.8 °C             |
| Zixi County (ZX)     | Chengshang village, Gaotian township | E 116°50'06.80"<br>N 27°49'31.22" | Red soil        | 100 m    | 1930 mm                  | 16.9 °C             |
| Jishui County (JS)   | Qiubi village, Shuinan township      | E 115°18'32.70"<br>N 27°00'49.74" | Yellow-red soil | 200 m    | 1527 mm                  | 18.8 °C             |
| Wan'an County (WA)   | Xiadong village, Gaopi township      | E 114°45'58.09"<br>N 26°32'33.81" | Yellow-red soil | 200 m    | 1335 mm                  | 18.4 °C             |
| Shangxia County (SY) | Xiuluo village, Ziyang township      | E 114°31'54.59"<br>N 26°04'20.93" | Brown soil      | 300 m    | 1497 mm                  | 18.8 °C             |
| Yudu County (YD)     | Anzixia village, Xianxia township    | E 115°33'38.14"<br>N 26°06'59.53" | Red soil        | 200 m    | 1507 mm                  | 19.7 °C             |
| Xinfeng County (XF)  | Shizipai village, Datangbu township  | E 114°55'40.14"<br>N 25°19'23.54" | Red soil        | 150 m    | 1492 mm                  | 19.2 °C             |

The morphological characteristics of each part of the oil camellia fruit are illustrated in Figure 1.

Twenty representative fruits of each cultivar were selected, and their morphological characteristics were measured immediately after harvest using a vernier caliper (Deli-DL91150; Deli Tools, Zhejiang, China). The fruit shape index was calculated as follows:

$$\text{Fruit shape index} = \left\{ \frac{\text{fruit height}}{[(\text{narrow diameter} + \text{wide diameter})/2]} \right\}. \quad [1]$$

Subsequently, the single fruit weight was determined using an electronic scale (CN-LQC10002; Youkeweite, Kunshan, China). The pericarp was carefully peeled with a knife or manually, and its weight was recorded separately from that of the seeds. The

pericarp samples were placed in paper bags, dried in an oven at 60 °C until reaching a constant weight, and reweighed. For the seed analysis, 20 representative seeds were selected, the weights of the remaining seeds were weighed after the seed coat and kernel had been shelled using a knife or pruner. The remaining seeds, shelled seed coat, and kernel were placed in paper bags dried in an oven at 60 °C until reaching a constant weight and then reweighed. The experiment was repeated three times to ensure reliability. The moisture content of the seeds, fruit pericarp, seed coat, and kernel were determined based on the weight change before and after drying.

The *CV* for fruit traits was calculated as the ratio of the standard deviation (*SD*) to the mean value and expressed as a proportionality to facilitate comparisons across different traits or datasets.

## Data analysis

SPSS software (version 19.0) was used for the difference correlation analysis, significance analysis ( $P < 0.05$ ), and principal component analysis. Graphs were generated using Origin 2021 software.

## Results

### Fruit morphology analysis

*Cultivar variations in fruit morphology.* The morphological analysis of fruits was conducted based on the following five parameters: fruit height; narrow diameter; wide diameter; ratio of narrow diameter to wide diameter; and the fruit shape index. These morphological characteristics were compared across five distinct cultivars (Table 2). Of the cultivars, CL53 exhibited the highest values for fruit height, narrow diameter, and wide diameter, and CL18 recorded the lowest

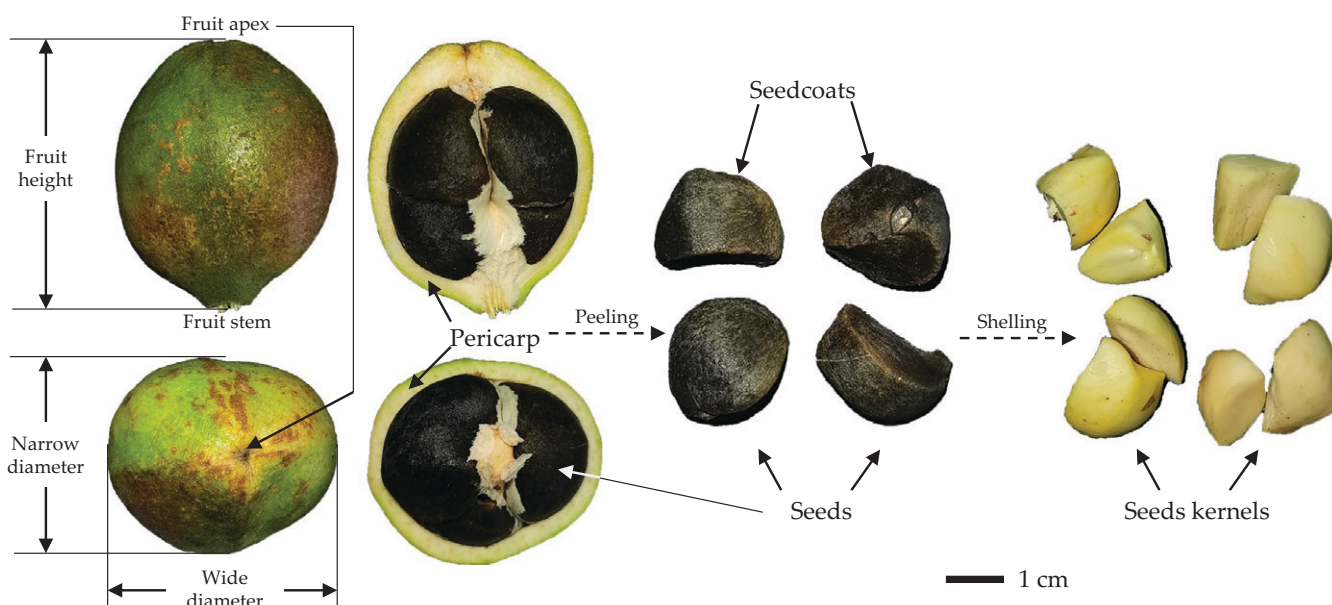


Fig. 1. The anatomical structure of oil camellia fruit.

Table 2. Fruit morphology of five Changlin oil camellia cultivars.

| Cultivar     | Fruit ht       |      |         | Narrow diam    |      |         | Wide diam      |      |         | Narrow/wide diam |      |         | Fruit shape index |                |         |
|--------------|----------------|------|---------|----------------|------|---------|----------------|------|---------|------------------|------|---------|-------------------|----------------|---------|
|              | Mean (mm)      | CV   | F value | Mean (mm)      | CV   | F value | Mean (mm)      | CV   | F value | Mean (mm)        | CV   | F value | Mean (mm)         | CV             | F value |
|              |                |      |         |                |      |         |                |      |         |                  |      |         |                   |                |         |
| CL53         | 41.11 ± 4.64 a | 0.11 | 19.53   | 35.58 ± 4.89 a | 0.14 | 15.1    | 37.77 ± 4.55 a | 0.12 | 14.36   | 0.94 ± 0.05 ab   | 0.05 | 6.19    | 1.13 ± 0.08 b     | 41.11 ± 4.64 a | 0.11    |
| CL40         | 36.66 ± 4.05 b | 0.11 | 19.5    | 30.92 ± 3.86 d | 0.12 | 14.03   | 33.15 ± 3.88 c | 0.12 | 22.37   | 0.92 ± 0.06 c    | 0.07 | 1.24    | 1.15 ± 0.10 a     | 36.66 ± 4.05 b | 0.11    |
| CL18         | 35.96 ± 4.46 b | 0.12 | 15.37   | 35.48 ± 4.77 a | 0.13 | 11.87   | 37.44 ± 4.44 a | 0.12 | 11.41   | 0.94 ± 0.07 b    | 0.07 | 6.64    | 0.98 ± 0.09 d     | 35.96 ± 4.46 b | 0.12    |
| CL4          | 40.36 ± 3.20 a | 0.08 | 4.81    | 34.16 ± 4.25 b | 0.12 | 14.46   | 36.44 ± 4.03 b | 0.11 | 8.15    | 0.93 ± 0.06 b    | 0.06 | 2.58    | 1.14 ± 0.11 ab    | 40.36 ± 3.20 a | 0.08    |
| CL3          | 36.06 ± 4.45 b | 0.12 | 21.22   | 32.43 ± 3.91 c | 0.12 | 19.76   | 33.50 ± 3.54 c | 0.11 | 18.46   | 0.95 ± 0.04 a    | 0.04 | 4.2     | 1.10 ± 0.10 c     | 36.06 ± 4.45 b | 0.12    |
| <b>Total</b> | 38.03 ± 4.74   | 0.12 | 24.42   | 33.71 ± 4.71   | 0.14 | 18.82   | 35.66 ± 4.54   | 0.13 | 19.71   | 0.94 ± 0.06      | 0.06 | 4.59    | 1.10 ± 0.11       | 38.03 ± 4.74   | 0.10    |

Different letters in the mean column indicate significant differences  $P < 0.05$ . The  $F$  value is the result of the analysis of variance of the fruit index of the same cultivar of different origins.

average fruit height; however, CL3 showed the lowest average values for both wide and narrow diameters. The ratio of narrow diameter to wide diameter, which serves as an indicator of the fruit's transverse shape and reflects seeds development within the ovary, was highest for CL3 and lowest for CL40. Additionally, CL18 was identified as a typical orange-type fruit, characterized by the smallest fruit shape index, whereas CL40 displayed the largest fruit shape index.

The  $CV$  for fruit height of CL4 was 0.08, whereas the  $CV$  values for the other cultivars ranged from 0.11 to 0.12. Minimal variation was observed in the  $CV$ s of narrow and wide diameters across all cultivars. CL3 exhibited the smallest  $CV$  for the ratio of narrow diameter to wide diameter, whereas CL18 had the largest for this parameter. Additionally, CL53 showed the lowest  $CV$  for the fruit shape index.

**Regional variations in fruit morphology.** Significant morphological variations were observed within the same cultivar in different geographical regions. For instance, the average fruit height of CL53 was the highest for YX CL53 (46.50 mm), whereas SY CL53 recorded the lowest fruit height (35.94 mm), which was slightly below that of CL18 (35.96 mm). The results of a detailed comparative analysis of fruit morphologies across cultivars and regions are presented in Fig. 2.

For CL53, regions with above-average fruit height included YX, PY, WA, YD, and XF. The narrow diameter exceeded the average of YX, PY, YD, and XF, whereas the wide diameter was above-average in YX, PY, JS, YD, and XF. YX exhibited the largest narrow-to-wide diameter ratio, whereas YS had the smallest. The regions with the highest and lowest fruit shape index values were YS and JS, respectively.

For CL40, regions with above-average fruit height were YX, DX, ZX, and YD. The narrow diameter was below-average in YS, WA, SY and XF, whereas the wide diameter exceeded the average in YS, ZX, WA, and SY. No statistical differences were observed in the narrow-to-wide diameter ratio or fruit shape index.

For CL18, regions with above-average fruit height included YX, PY, DX, YD, and XF. The narrow and wide diameters exceeded the average in YX, DX, JS, YD, and XF. DX recorded the largest narrow-to-wide diameter ratio, whereas YS exhibited the smallest. No statistical differences were observed in the fruit shape index.

For CL4, regions with below-average fruit height and narrow diameters were YS, ZX, and JS; JS had an above-average narrow diameter. The wide diameters exceeded the average in YX, PY, DX, JS, and XF. PY and YS exhibited the largest and smallest narrow-to-wide diameter ratios, respectively, whereas YS and JS recorded the highest and lowest fruit shape index, respectively.

For CL3, regions with below-average fruit height included YS, ZX, JS, and XF. The narrow diameter did not exceed the average in YS, ZX, WA, and XF. The wide diameter

was above-average in YX, PY, DX, WA, and YD. YX and JS recorded the largest and smallest narrow-to-wide diameter ratios, respectively, whereas JS and YS exhibited the highest and lowest fruit shape index, respectively.

**Fruit morphology analysis.** YX CL53 had the highest fruit height, whereas YS CL3 had the lowest. YD CL18 had the largest narrow and wide diameters, whereas SY CL40 had the smallest. DX CL18 had the largest narrow-to-wide diameter ratio, and YS CL18 had the smallest. YS CL4 had the largest fruit shape index, whereas JS CL18 had the smallest.

## Fruit weight analysis

**Cultivar variations in fruit weight.** The oil camellia fruit consists of three primary components: the pericarp, seed coat, and seed kernel. In this study, five weight traits (fruit, pericarp, seeds, seed coat, and seed kernel) were analyzed (Table 3). Of the evaluated cultivars, CL53 had the highest values for all weight traits. CL40 had the lowest fruit, seeds, seed coat, and seed kernel weights, whereas CL3 had the lowest pericarp weight.

Differences were observed in the weight components of fruits across all cultivars. The  $CV$  for fruit, seeds, and kernel weights were highest in CL53 and lowest in CL18. For pericarp weight, the  $CV$  was highest in CL40 and lowest in CL4. The  $CV$  for seed coat weight was highest in CL40 and lowest in CL18.

There were regional variations in the weight components of fruits of the same cultivar (Table 4). Camellia oil is derived from the seed kernel, and its yield is directly proportional to the weight of the seeds and seed kernel within the fruit. The pericarp-to-fruit ratios, from smallest to largest, were as follows: CL3, 45.09%; CL53, 48.02%; CL18, 51.77%; CL4, 53.81%; and CL40, 59.27%. The seed coat to fruit ratio (21.63%) and seed coat to seed ratio (39.14%) were highest in CL3, whereas CL40 had the lowest values for these parameters (12.34% and 30.31%, respectively). The kernel-to-fruit weight ratios, ranked from largest to smallest, were as follows: CL53, 35.10%; CL3, 33.28%; CL18, 30.95%; CL4, 30.17%; and CL40, 28.38%.

**Regional variations in fruit weight.** The weight of each part of fruit within the same cultivar exhibited considerable variation depending on the location (Fig. 3).

For CL53, regions with above-average weight of fruit, pericarp, and seeds included YX, PY, YD, and XF. The seed coat and kernel weight exceeded the average in YX, JS, YD, and XF. Regions with above-average pericarp-to-fruit weight ratios included PY, YS, ZX, and WA. The seed coat-to-fruit weight ratio was below average in PY, YS, ZX, and SY. No significant differences were observed in the kernel-to-fruit weight ratio.

For CL40, regions with above-average fruit weight included YX, PY, DX, ZX, and YD. The pericarp weight exceeded the average in YX, PY, DX, and ZX, whereas the seed weight was below-average in YS, WA,

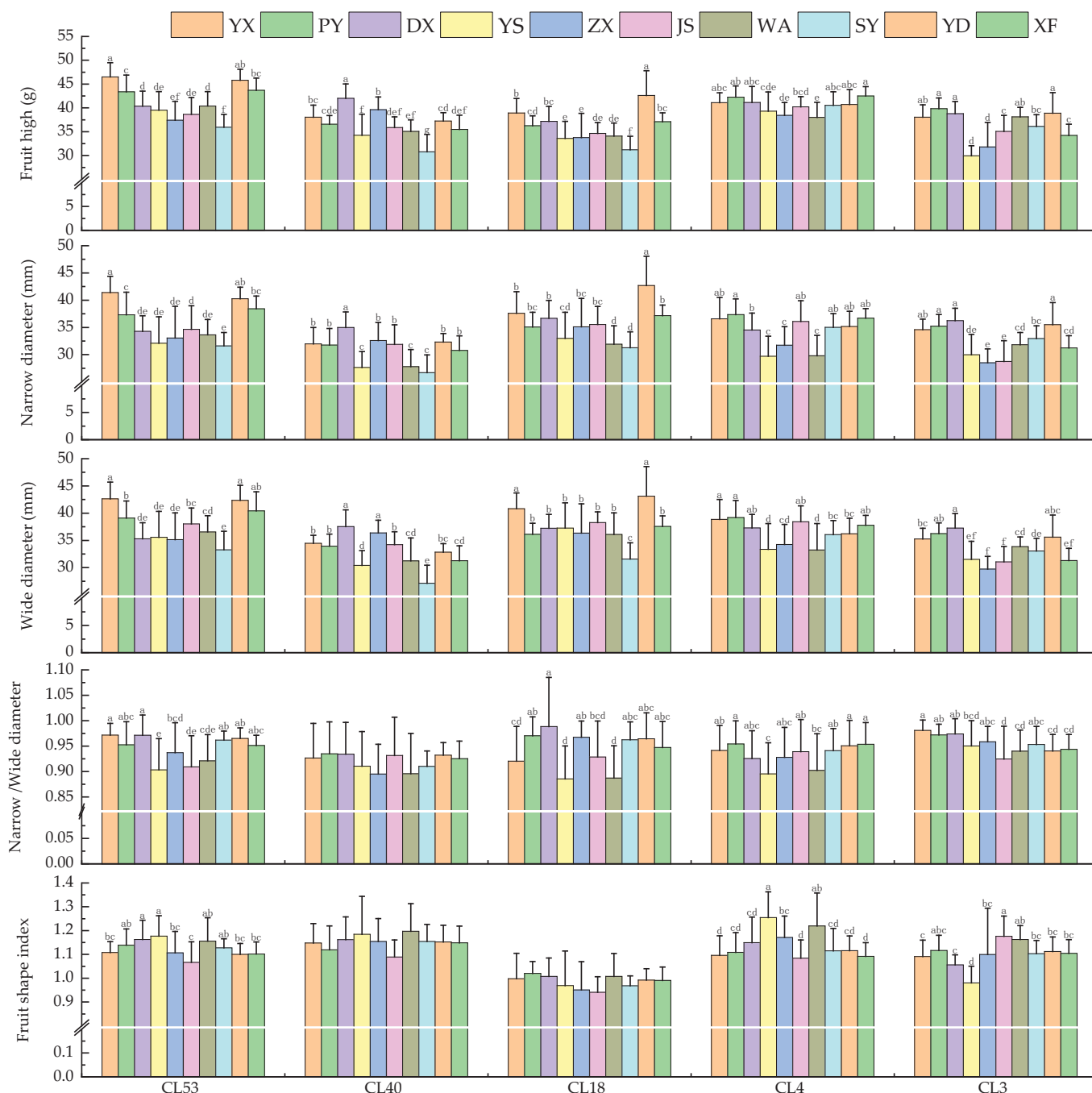


Fig. 2. Fruit morphology of different cultivars in different regions. Different letters indicate significant differences ( $P < 0.05$ ) in the same cultivar across different regions.

SY, and XF. The seed coat and kernel weight exceeded the average in DX, ZX, JS, and YD, with YX also showing above-average seed kernel weight. Regions with above-average pericarp-to-fruit weight ratios included PY, DX, YS, SY, and XF, whereas the seed coat-to-fruit weight ratio was above-average in DX, ZX, JS, SY, and YD. The seed kernel-to-fruit weight ratio was below-average in PY, DX, and WA.

For CL18, regions with above-average fruit weight included YX, ZX, YD, and XF. The pericarp weight exceeded the average in YX, JS, YD, and XF, whereas the seed weight was above-average in YX, ZX, and

YD. The seed coat weight exceeded the average in YX, PY, YD, and XF, whereas the seed kernel weight exceeded the average in YX, ZX, and YD. Regions with above-average pericarp-to-fruit ratios included YX, YS, WA, SY, and XF, whereas the seed coat-to-fruit weight ratio was below-average in YX, YS, WA, and SY. The seed kernel-to-fruit weight ratio was below-average in JS, WA, SY, and XF.

For CL4, regions with below-average fruit weight of fruit and seeds included YS, ZX, and WA. The pericarp weight exceeded the average in YX, PY, JS, and XF. The seed coat and kernel weight did not exceed the

average in YS, ZX, and WA, and DX showed a below-average seed coat weight. Regions with above-average pericarp-to-fruit weight ratios included YS, ZX, JS, and WA, whereas the seed coat-to-fruit weight ratio was below-average in DX, YS, and ZX. The seed kernel to fruit weight ratio was below-average in YS, ZX, JS, and WA.

For CL3, regions with below-average fruit weight included YS, ZX, JS, and XF. The pericarp and seed coat weight were below-average in YS, ZX, JS, and SY, whereas the seed weight exceeded the average in YX, PY, DX, SY, and YD. The kernel weight exceeded the average in YX, PY, DX, SY, and

Table 3. Fruit weight composition of five Changlin oil camellia cultivars.

| Cultivars    | Fruit wt       |      |         | Pericarp wt    |      |         | Seeds wt       |      |         | Seed coat wt   |      |         | Seed kernel wt |      |         |
|--------------|----------------|------|---------|----------------|------|---------|----------------|------|---------|----------------|------|---------|----------------|------|---------|
|              | Mean (g)       | CV   | F value | Mean (g)       | CV   | F value | Mean (g)       | CV   | F value | Mean (g)       | CV   | F value | Mean (g)       | CV   | F value |
| CL53         | 29.29 ± 8.37 a | 0.29 | 11.36   | 13.96 ± 3.87 a | 0.28 | 9.77    | 15.31 ± 4.89 a | 0.32 | 10.59   | 4.92 ± 1.87 a  | 0.38 | 8.80    | 10.21 ± 3.12 a | 0.31 | 12.22   |
| CL40         | 20.65 ± 5.37 c | 0.26 | 19.63   | 12.15 ± 3.45 c | 0.28 | 17.08   | 8.48 ± 2.5 c   | 0.29 | 16.36   | 2.65 ± 1.07 d  | 0.40 | 14.09   | 6.11 ± 1.71 d  | 0.28 | 9.49    |
| CL18         | 25.96 ± 3.34 b | 0.13 | 7.08    | 13.37 ± 1.72 b | 0.13 | 6.31    | 12.55 ± 1.81 b | 0.14 | 6.11    | 4.46 ± 0.68 bc | 0.15 | 6.31    | 8.03 ± 1.28 b  | 0.16 | 6.93    |
| CL4          | 25.78 ± 3.62 b | 0.14 | 10.13   | 13.72 ± 1.6 ab | 0.12 | 7.26    | 11.97 ± 2.31 b | 0.19 | 11.87   | 4.15 ± 0.97 c  | 0.23 | 17.33   | 7.78 ± 1.43 b  | 0.18 | 10.13   |
| CL3          | 21.39 ± 4.19 c | 0.2  | 26.24   | 9.5 ± 1.3 d    | 0.14 | 34.96   | 11.93 ± 3.01 b | 0.25 | 33.52   | 4.69 ± 1.29 ab | 0.27 | 40.96   | 7.18 ± 1.76 c  | 0.24 | 24.38   |
| <b>Total</b> | 24.56 ± 7.27   | 0.30 | 18.65   | 12.65 ± 3.73   | 0.29 | 16.03   | 12.01 ± 4.41   | 0.37 | 21.79   | 4.07 ± 1.64    | 0.40 | 14.05   | 7.83 ± 2.79    | 0.36 | 11.65   |

The *F* value is the result of the analysis of variance of the fruit index of the same cultivar of different origins.

Table 4. Weight ratio of each part of the fruit in five Changlin oil camellia cultivars.

| Cultivars    | Pericarp/fruit |      | Seedcoats/fruit |      | Kernel/fruit    |      | Seedcoats/seed  |      |
|--------------|----------------|------|-----------------|------|-----------------|------|-----------------|------|
|              | Mean (%)       | CV   | Mean (%)        | CV   | Mean (%)        | CV   | Mean (%)        | CV   |
| CL53         | 48.02 ± 1.80 c | 0.04 | 16.88 ± 0.93 b  | 0.05 | 35.10 ± 1.17 a  | 0.03 | 32.47 ± 1.10 cd | 0.03 |
| CL40         | 59.27 ± 3.12 a | 0.05 | 12.34 ± 1.59 c  | 0.13 | 28.38 ± 2.44 d  | 0.09 | 30.31 ± 2.99 d  | 0.10 |
| CL18         | 51.77 ± 2.35 b | 0.05 | 17.28 ± 1.73 b  | 0.10 | 30.95 ± 1.79 c  | 0.06 | 35.8 ± 2.76 b   | 0.08 |
| CL4          | 53.81 ± 3.32 b | 0.06 | 16.02 ± 2.23 b  | 0.14 | 30.17 ± 1.98 cd | 0.07 | 34.55 ± 3.49 bc | 0.10 |
| CL3          | 45.09 ± 4.46 d | 0.10 | 21.63 ± 3.36 a  | 0.16 | 33.28 ± 1.98 b  | 0.06 | 39.14 ± 4.12 a  | 0.11 |
| <b>Total</b> | 51.63 ± 5.89   | 0.11 | 16.87 ± 3.66    | 0.22 | 31.58 ± 3.07    | 0.10 | 34.38 ± 4.28    | 0.12 |

The *F* value is the result of the analysis of variance of the fruit index of the same cultivar of different origins.

YD. Regions with above-average pericarp-to-fruit weight ratios included YS, ZX, JS, WA, and XF, whereas the seed coat-to-fruit weight ratio was below-average in DX, YS, and XF. The seed kernel to fruit weight ratio was above-average in YX, PY, DX, SY, and YD.

**Fruit weight analysis.** A detailed comparison of fruit weight components across the five cultivars in the 10 regions was conducted (Fig. 3). Poyang CL53 had the largest pericarp, seed coat, and seed kernel weights, whereas the smallest pericarp, seed coat, and kernel weights were found for Zixi CL3, YS CL4, and SY CL40, respectively. The pericarp-to-fruit weight ratio was highest in

WA CL40 (64.04%) and lowest in DX CL3 (41.28%). The seed coat-to-fruit weight ratio was highest in YX CL53 (24.12%) and lowest in ZX CL4 (10.06%). The seed coat-to-seed weight ratio was highest in WA CL3 (46.21%) and lowest in ZX CL4 (25.69%). The kernel-to-fruit weight ratio was highest in DX CL3 (37.47%) and lowest in DX CL40 (24.86%).

#### Fruit moisture content analysis

**Cultivar variations in fruit moisture content.** The moisture content of oil camellia fruit was negatively correlated with oil content, indicating that moisture levels directly influenced oil yield. The analysis of moisture

content encompassed four distinct components, PMC, SMC, SCMC, and SKMC, and the average moisture contents for these components were 71.26%, 49.19%, 28.12%, and 57.12%, respectively (Table 5).

Of the cultivars analyzed, CL53 exhibited the highest PMC (74.20%) and SMC (54.22%), whereas CL40 displayed the lowest values for these parameters (67.43% and 42.19%, respectively). For SCMC, the highest value was observed in CL4 (30.65%), whereas the lowest was observed in CL40 (24.9%). Similarly, CL4 demonstrated the highest SKMC (64.5%), whereas CL18 had the lowest (48.28%).

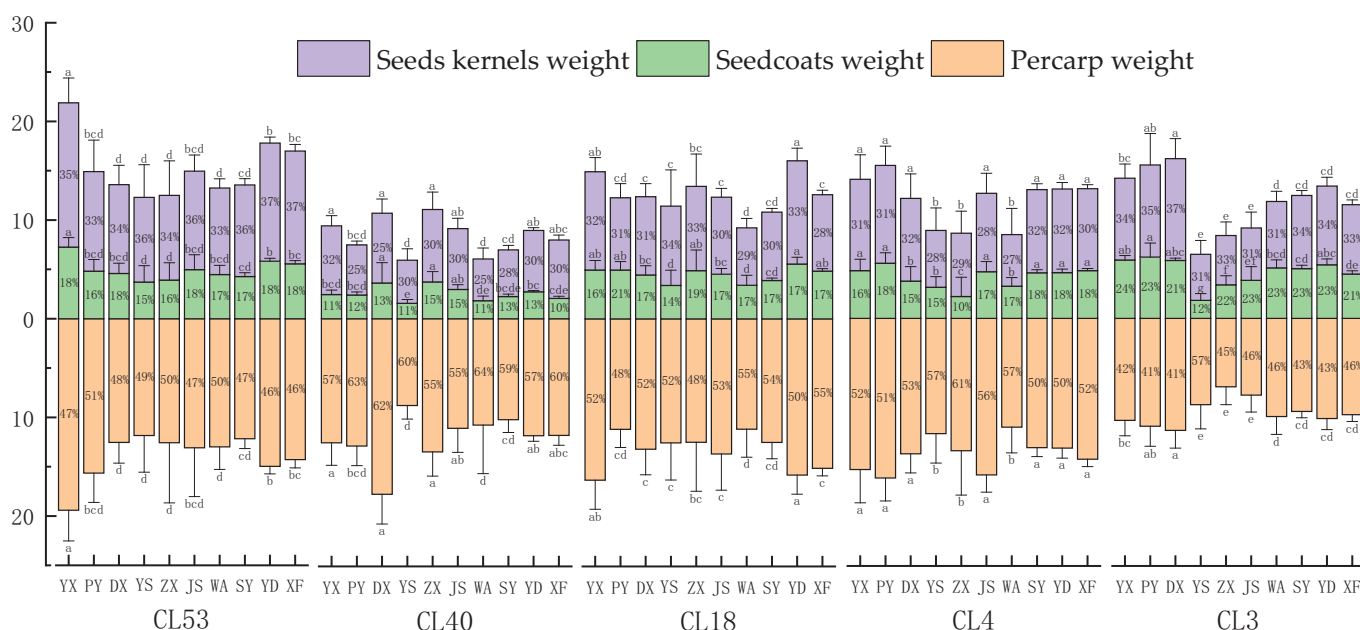


Fig. 3. Fruit weight components of different cultivars in different regions (the percentages in the bar chart are the weight ratios of each fruit component to the fruit). Different letters indicate significant differences ( $P < 0.05$ ) in the same cultivar across different regions.

Table 5. Moisture content of each fruit component in five Changlin oil camellia cultivars.

| Cultivar | PMC             |      |         | SMC             |      |         | SCMC            |      |         | SKMC           |      |         |
|----------|-----------------|------|---------|-----------------|------|---------|-----------------|------|---------|----------------|------|---------|
|          | Mean (%)        | CV   | F value | Mean (%)        | CV   | F value | Mean (%)        | CV   | F value | Mean (%)       | CV   | F value |
| CL53     | 74.20 ± 3.63 a  | 0.05 | 18.15   | 54.22 ± 6.83 a  | 0.13 | 55.59   | 28.25 ± 2.83 ab | 0.10 | 3.24    | 59.37 ± 6.75 b | 0.11 | 15.93   |
| CL40     | 67.43 ± 5.68 c  | 0.08 | 27.51   | 50.21 ± 5.14 b  | 0.10 | 10.28   | 24.9 ± 4.88 c   | 0.20 | 15.27   | 55.91 ± 6.63 b | 0.12 | 46.06   |
| CL18     | 71.13 ± 3.86 b  | 0.05 | 20.17   | 42.19 ± 4.7 d   | 0.11 | 111.86  | 29.26 ± 4.19 ab | 0.14 | 4.78    | 48.28 ± 6.77 c | 0.14 | 14.88   |
| CL4      | 72.30 ± 2.06 ab | 0.03 | 12.17   | 53.07 ± 5.78 ab | 0.11 | 69.73   | 30.65 ± 5.28 a  | 0.17 | 60.95   | 64.5 ± 7.48 a  | 0.12 | 46.71   |
| CL3      | 71.23 ± 5.49 b  | 0.08 | 42.87   | 46.23 ± 4.09 c  | 0.09 | 102.55  | 27.54 ± 6.68 bc | 0.24 | 63.90   | 57.56 ± 8.99 b | 0.16 | 126.26  |
| Total    | 71.26 ± 5.06    | 0.07 | 29.66   | 49.19 ± 7.13    | 0.14 | 52.25   | 28.12 ± 5.67    | 0.20 | 14.55   | 57.12 ± 9.31   | 0.16 | 43.26   |

The *F* value is the result of the analysis of variance of the fruit index of the same cultivar of different origins.

PMC = pericarp moisture content; SMC = seed moisture content; SCMC = seed coat moisture content; SKMC was seed kernel moisture content, the same blow.

The *CV* for moisture content across different fruit components was also evaluated. The highest *CV* for PMC was observed in CL40, whereas the lowest was observed in CL53. For SMC, the highest *CV* was noted in CL53, and the lowest was noted in CL3. CL3 had the largest *CV* for both SCMC and SKMC, whereas CL53 displayed the lowest *CV* for these components.

*Regional variations in fruit moisture content.* Regional variations in the moisture content of fruits from the same cultivar were evident (Fig. 4).

For CL53, regions with below-average PMC and SCMC were limited to SY, whereas the SMC and SKMC exceeded the average in YS, JS, WA, and YD.

For CL40, regions with below-average PMC included YS, ZX, SY, and XF. The SMC was above-average in DX, YS, JS, WA, and YD. The SCMC exceeded the average in YX, DX, ZX, JS, and WA, whereas the SKMC was above-average in YS, JS, WA, YD, and XF.

For CL18, regions with below-average PMC included YS and SY. The SMC exceeded

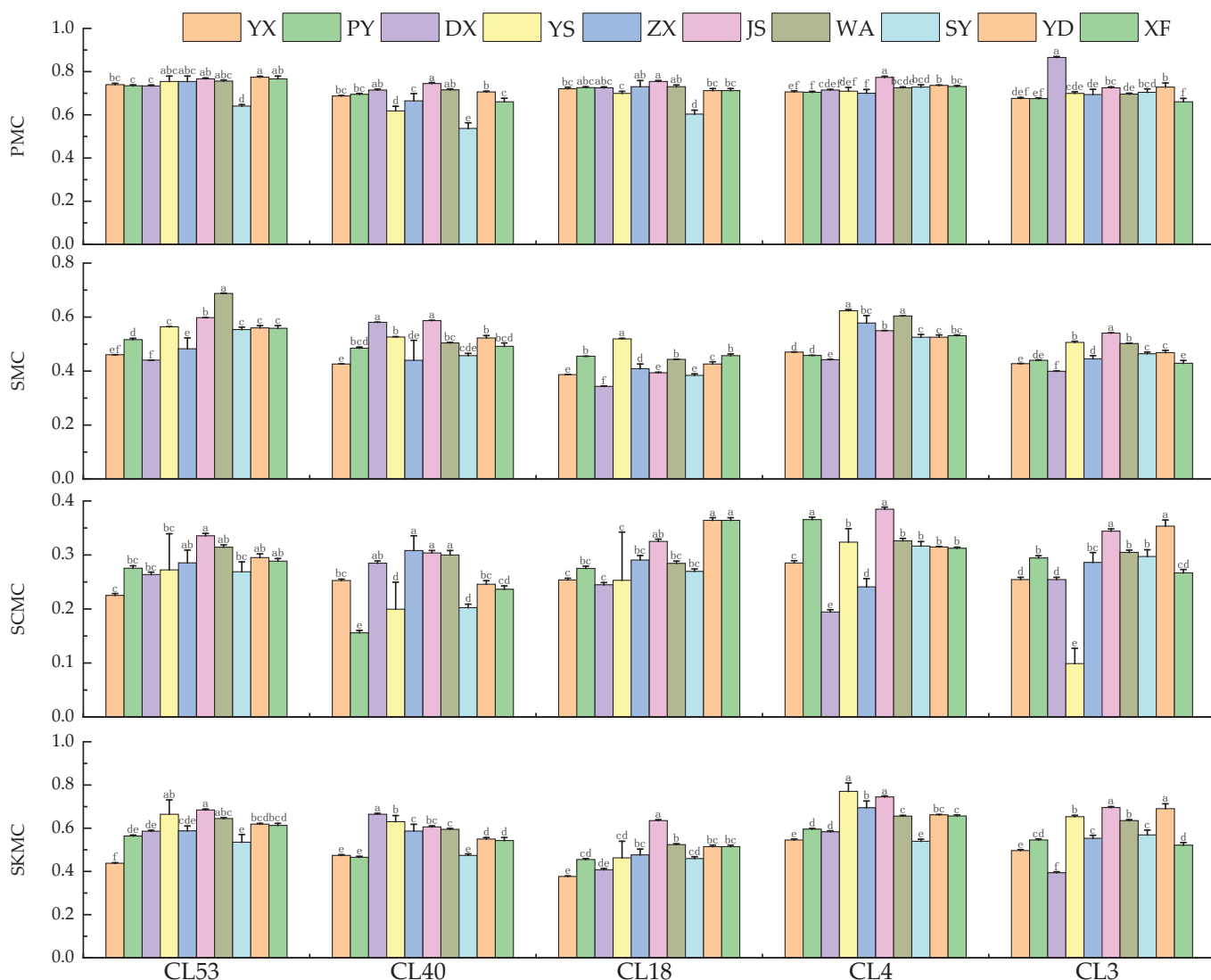


Fig. 4. The moisture content of each fruit component of different cultivars in different regions. Different letters indicate significant differences ( $P < 0.05$ ) in the same cultivar across different regions.

the average in PY, YS, WA, YD, and XF. The SCMC was above-average in JS, YD, and XF, whereas the SKMC exceeded the average in JS, WA, YD, and XF.

For CL4, minimal variation in PMC was observed across regions. Regions with below-average PMC included YX, PY, DX, SY, and YD. The SMC was above-average in DX, YS, JS, WA, and YD. The SCMC was below-average in YX, DX, and ZX, whereas the SKMC was below-average in YX, PY, DX, and SY.

For CL3, regions with above-average PMC included DX, JS, and YD. The SMC was below-average in YX, PY, DX, ZX, and XF. The SCMC was below-average in YX, DX, YS, and XF, whereas the SKMC exceeded the average in YS, JS, WA, and YD.

**Fruit moisture content analysis.** Differences in moisture content were observed across different fruit components within the same cultivar grown in different regions (Fig. 4). DX CL3 and SY CL40 exhibited the highest and lowest PMC, respectively. WA CL53 and DX CL18 displayed the highest and lowest SMC, respectively. JS CL4 and YS CL3 had the highest and lowest SCMC, respectively, whereas YS CL4 and YX CL18 demonstrated the highest and lowest SKMC, respectively.

### Primary economic fruit traits analysis

**Cultivar variations in primary economic fruit traits.** The primary economic traits of oil camellia fruit include 100-FSW, 100-DSW, DS/FF, DK/DS, and DK/FF. The average values for these traits were 296.37 g, 147.99 g, 49.19%, 54.68%, and 12.98%, respectively (Table 6).

Of the five cultivars analyzed, CL53 exhibited the highest 100-FSW (384.62 g), whereas CL3 had the lowest (230.17 g). The 100-DSW values, ranked from highest to lowest, were as follows: CL53, 172.31 g; CL18, 159.9 g; CL4, 150.34 g; CL40, 137.42 g; and CL3, 122.84 g. The highest DS/FF ratio was observed in CL3 (29.47%), whereas the lowest was observed in CL40 (21.31%). For DK/DS, CL40 had the highest ratio (60.85%), and CL3 had the lowest (46.24%). The DK/FF ratios, ranked from highest to lowest, were as follows: CL18, 16.32%; CL53, 13.37%; CL3, 13.18%; CL40, 12.23%; and CL4, 10.25%.

The CVs for 100-FSW and 100-DSW were highest in CL40, whereas the CV for 100-FSW was lowest in CL4; however, for 100-DSW, it was lowest in CL18. The CV for DS/FF was highest in CL53 and lowest in CL18. For DK/DS, the CV was highest in CL4 and lowest in CL40. The CV for DK/FF was highest in CL4; however, it was lowest in CL53.

**Regional variations in fruit primary economic traits.** Economic traits of fruits from the same cultivar, which are associated with fruit morphology, weight, and moisture content, exhibited substantial regional variation in the same fruit cultivar (Fig. 5).

For CL53, regions with below-average 100-FSW included YX, PY, DX, and SY. The 100-DSW exceeded the average in DX, YS, ZX, YD, and XF. Regions with above-average DS/FF included YX, JS, SY, YD, and XF, whereas the DK/DS was above-average in YX, PY, ZX, and SY. The DK/FF was below-average in YS, JS, and WA.

For CL40, regions with above-average 100-FSW and 100-DSW included DX, ZX, and WA; YX also showed above-average 100-DSW. Regions with above-average DS/FF included YX, ZX, WA, and SY, whereas the DK/DS was above-average in YX, PY, SY, YD, and XF. The DK/FF was below-average in DX, YS, JS, and WA.

For CL18, regions with above-average 100-FSW included PY, ZX, WA, YD, and XF, whereas the 100-DSW was below-average in PY, YS, JS, and SY. Regions with below-average DS/FF included DX, YS, and XF, whereas the DK/DS was above-average in YX, DX, and YS. The DK/FF was below-average in JS, WA, YD, and XF.

For CL4, regions with above-average 100-FSW included YX, YS, ZX, JS, and SY, whereas the 100-DSW was below-average in YS, JS, WA, and XF. Regions with above-average DS/FF included YX, PY, DX, SY, and YD, whereas the DK/DS was above-average in YS, DX, ZX, and SY. The DK/FF was below-average in YS, ZX, JS, and WA.

For CL3, regions with below-average 100-FSW included YS, ZX, and XF, whereas the 100-DSW was below-average in YS, ZX, WA, and XF. Regions with below-average DS/FF included YS, ZX, JS, and WA, whereas the DK/DS was below-average in YX, PY, DX, YS, ZX, and SY. The DK/FF was below-average in YS, JS, WA, and YD.

**Fruit primary economic traits analysis.** The 100-FSW of WA CL53 was the largest,

whereas that of ZX CL3 was the smallest. The 100-DSW of ZX CL53 was the largest, and that of YS CL3 was the smallest. The DS/FF from DX CL3 was the highest, and that of WA CL40 was the lowest. The DK/DS of YX CL18 was the highest, and that of YS CL4 was the lowest. The DK/FF of DX CL3 was the highest, and that of YS CL4 was the lowest.

### Correlation analysis of fruit traits

Correlation analysis of the 19 fruit traits across all samples revealed strong positive correlations in fruit morphology (fruit height, narrow diameter, and wide diameter) and fruit weight (including fruit, pericarp, seeds, seed coat, kernel, fresh seed weight, and dry seed weight). Specifically, fruit height exhibited a positive correlation with PMC and SCMC. Fruit weight was strongly positively correlated with PMC, SCMC, DK/DS, and DK/FF. The PMC demonstrated strong positive correlations with all fruit morphological and weight traits, except for pericarp weight. The SMC was negatively correlated with narrow and wide diameters, DS/FF, and DK/FF, but it was positively correlated with the fruit morphological traits, SKMC, and 100-FSW. Additional correlations among the remaining indicators are detailed in Table 7.

### Principal component analysis and evaluation of fruit characteristics

A principal component analysis was applied to evaluate 19 indicators of fruit. The original data were standardized using the Z-score method and subsequently examined through Kaiser–Meyer–Olkin and Bartlett’s sphericity tests. Based on the aforementioned results, six fruit traits (narrow and wide diameters of fruit, fruit shape index, PMC, SMC, SKMC, and DK/DS) with a CV less than 10% and low intercorrelation were excluded. Factor analyses of the remaining 13 fruit traits were subsequently conducted. Three principal components with eigenvalues greater than 1.0 and a cumulative contribution ratio of 83.77% were extracted (Table 8). The first principal component (f1) had an eigenvalue of 7.483 and a contribution ratio of 57.56%. The average load coefficients for both fruit morphology and weight indices exceeded 0.5, indicating that this principal component primarily reflected fruit size and weight. The second principal component (f2) had an eigenvalue of

Table 6. Important economic fruit traits of five Changlin oil camellia cultivars.

| Cultivars    | 100 FSW        |           |                |        | 100 DSW        |           |                |        | DS/FF        |           |                |       | DK/DS        |           |                |              | DK/FF    |           |                |  |
|--------------|----------------|-----------|----------------|--------|----------------|-----------|----------------|--------|--------------|-----------|----------------|-------|--------------|-----------|----------------|--------------|----------|-----------|----------------|--|
|              | Mean (g)       | <i>CV</i> | <i>F</i> value |        | Mean (g)       | <i>CV</i> | <i>F</i> value |        | Mean (g)     | <i>CV</i> | <i>F</i> value |       | Mean (g)     | <i>CV</i> | <i>F</i> value |              | Mean (g) | <i>CV</i> | <i>F</i> value |  |
| CL53         | 384.62 ± 64.64 | a         | 0.17           | 493.65 | 172.31 ± 20.42 | a         | 0.12           | 26.94  | 24.18 ± 4.70 | b         | 0.19           | 11.90 | 60.34 ± 7.84 | 0.13      | 68.62          | 13.37 ± 2.37 | b        | 0.18      | 16.13          |  |
| CL40         | 274.05 ± 46.63 | c         | 0.17           | 303.06 | 135.42 ± 28.74 | c         | 0.21           | 26.24  | 21.31 ± 2.94 | c         | 0.14           | 3.00  | 60.85 ± 5.97 | 0.10      | 14.62          | 12.23 ± 3.25 | c        | 0.27      | 32.05          |  |
| CL18         | 274.49 ± 28.22 | c         | 0.10           | 149.90 | 159.02 ± 16.13 | b         | 0.10           | 99.40  | 28.37 ± 3.17 | a         | 0.11           | 2.35  | 56.97 ± 8.65 | 0.15      | 14.43          | 16.32 ± 3.77 | a        | 0.23      | 16.94          |  |
| CL4          | 318.54 ± 30.83 | b         | 0.10           | 261.76 | 150.34 ± 19.55 | b         | 0.13           | 63.13  | 22.79 ± 3.85 | c         | 0.17           | 9.10  | 49.01 ± 7.45 | 0.15      | 17.15          | 10.25 ± 3.34 | d        | 0.33      | 47.96          |  |
| CL3          | 230.17 ± 33.34 | d         | 0.14           | 132.40 | 122.84 ± 20.01 | d         | 0.16           | 140.97 | 29.47 ± 4.66 | a         | 0.16           | 39.70 | 46.24 ± 5.43 | 0.12      | 5.03           | 13.18 ± 3.48 | bc       | 0.26      | 19.25          |  |
| <b>Total</b> | 296.37 ± 67.37 |           | 0.23           | 55.53  | 147.99 ± 27.36 |           | 0.18           | 24.76  | 25.4 ± 5.59  |           | 0.22           | 28.65 | 54.68 ± 9.60 | 0.18      | 36.77          | 12.98 ± 3.97 |          | 0.31      | 54.85          |  |

The F value is the result of the analysis of variance of the fruit index of the same cultivar of different origins.

100 FSW = weight of 100 fresh seeds; DK/DS = ratio of dry kernel weight to dry seed weight; DK/FF = ratio of dry kernel weight to fresh fruit weight; 100 DSW = weight of 100 dry seeds; DS/FF = ratio of dry seed weight to fresh fruit weight.

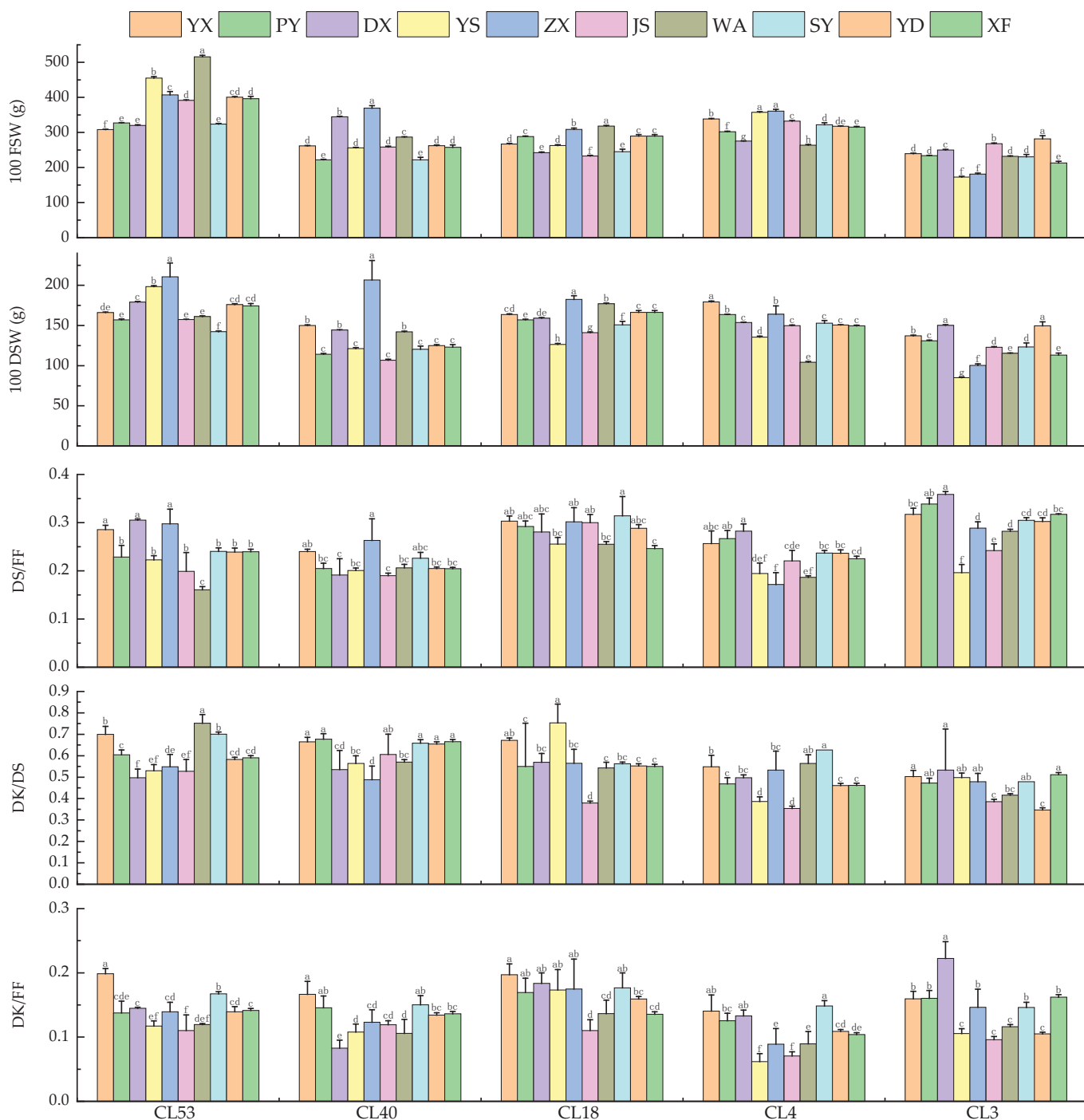


Fig. 5. Important economic fruit traits of different cultivars in different regions. Different letters indicate significant differences ( $P < 0.05$ ) in the same cultivar across different regions.

2.299 and a contribution of 17.69%, with load coefficients for DS/FF and DK/FF both exceeding 0.8, suggesting that this component mainly represents the characteristics of seed and kernel solid content within the fruit. The third principal component (f3) had an eigenvalue of 1.108, a contribution ratio of 8.52%, and a load coefficient for SCMC greater than 0.8.

According to the characteristic value (i.e., the contribution ratio of each principal component) and load coefficient of the fruit trait index, the comprehensive score of the fruit

trait was calculated. The score matrix was obtained by dividing the load coefficient by the square root of the eigenvalues of the corresponding principal components. The score matrix was multiplied by the standardized data and summed to obtain the scores of each principal component for each cultivar. The score of the principal component was multiplied by the ratio of the eigenvalues of the principal component to the eigenvalues of all selected principal components and summed to obtain a comprehensive evaluation score (Table 9).

The comprehensive comparison indicated that all five cultivars ranked within the top 10 for comprehensive scores of fruit traits. The top two cultivars were CL53 from YX and YS, with the highest-scoring CL4 ranked third in YX and the highest-scoring CL3 ranked fourth in PY. Cultivars ranked fifth to ninth were YS CL18, ZX CL53, WA CL4, SY CL3, and YD CL18, whereas the highest-scoring CL40 was ranked tenth in PY.

Currently, the cultivar configuration for *C. oleifera* in Jiangxi Province is structured as follows: the three main promoted cultivars

Table 7. Correlation analysis of fruit traits.

| Fruit characteristics | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | 11     | 12     | 13     | 14     | 15     | 16    | 17     | 18     | 19 |
|-----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|----|
| 1                     | 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |       |        |        |    |
| 2                     | 0.75** | 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |       |        |        |    |
| 3                     | 0.78** | 0.94** | 1      |        |        |        |        |        |        |        |        |        |        |        |        |       |        |        |    |
| 4                     | 0.22   | 0.53** | 0.28*  | 1      |        |        |        |        |        |        |        |        |        |        |        |       |        |        |    |
| 5                     | 0.28*  | 0.41*  | 0.34*  | 0.35*  | 1      |        |        |        |        |        |        |        |        |        |        |       |        |        |    |
| 6                     | 0.8**  | 0.92** | 0.91** | 0.41** | -0.24  | 1      |        |        |        |        |        |        |        |        |        |       |        |        |    |
| 7                     | 0.71** | 0.76** | 0.81** | 0.15   | -0.16  | 0.87** | 1      |        |        |        |        |        |        |        |        |       |        |        |    |
| 8                     | 0.72** | 0.88** | 0.82** | 0.53** | -0.25  | 0.92** | 0.61** | 1      |        |        |        |        |        |        |        |       |        |        |    |
| 9                     | 0.6**  | 0.8**  | 0.7**  | 0.59** | 0.29*  | 0.78** | 0.42** | 0.93** | 1      |        |        |        |        |        |        |       |        |        |    |
| 10                    | 0.74** | 0.87** | 0.84** | 0.47** | -0.22  | 0.94** | 0.68** | 0.98** | 0.84** | 1      |        |        |        |        |        |       |        |        |    |
| 11                    | 0.48** | 0.5**  | 0.58** | 0.14   | -0.11  | 0.42** | 0.28   | 0.46** | 0.42** | 0.45** | 1      |        |        |        |        |       |        |        |    |
| 12                    | 0.24   | -0.19  | -0.06  | 0.43** | 0.54** | -0.08  | 0.01   | -0.14  | -0.22  | -0.09  | 0.19   | 1      |        |        |        |       |        |        |    |
| 13                    | 0.34*  | 0.32*  | 0.33*  | -0.02  | 0.01   | 0.28*  | 0.21   | 0.3*   | 0.45** | 0.23   | 0.32*  | 0.18   | 1      |        |        |       |        |        |    |
| 14                    | 0.18   | -0.2   | -0.1   | 0.34*  | 0.48** | -0.19  | -0.11  | -0.22  | -0.17  | -0.21  | 0.16   | 0.69** | 0.37** | 1      |        |       |        |        |    |
| 15                    | 0.56** | 0.29*  | 0.43** | -0.21  | 0.27   | 0.44** | 0.44** | 0.35*  | 0.19   | 0.43** | 0.39** | 0.57** | 0.35*  | 0.38** | 1      |       |        |        |    |
| 16                    | 0.5**  | 0.52** | 0.59** | 0.08   | -0.11  | 0.6**  | 0.56** | 0.51** | 0.39** | 0.57** | 0.31*  | -0.13  | 0.29*  | -0.07  | 0.72** | 1     |        |        |    |
| 17                    | -0.14  | 0.22   | 0.11   | 0.42** | 0.43** | 0.17   | -0.11  | 0.36** | 0.5**  | 0.27   | -0.01  | 0.77** | 0.06   | 0.53** | 0.35*  | 0.19  | 1      |        |    |
| 18                    | 0.22   | 0.41** | 0.42** | 0.09   | -0.27  | 0.33*  | 0.44** | 0.19   | 0      | 0.27   | 0.11   | -0.24  | -0.17  | 0.49** | 0.06   | 0.31* | 0.02   | 1      |    |
| 19                    | -0.07  | 0.31*  | 0.19   | 0.48** | 0.47** | 0.3*   | 0.09   | 0.42** | 0.36** | 0.42** | -0.05  | 0.65** | 0.31*  | 0.94** | 0.28*  | 0.14  | 0.62** | 0.41** | 1  |

Numbers in the table correspond to the fruit characteristics as follows: 1 = fruit height; 2 = narrow diameter; 3 = wide diameter; 4 = narrow/wide diameter; 5 = fruit shape index; 6 = fruit weight; 7 = pericarp weight; 8 = seed weight; 9 = seed coat weight; 10 = seed kernel weight; 11 = PMC; 12 = SMC; 13 = SMC; 14 = SKMC; 15 = 100 FSW; 16 = 100 DS; 17 = DS/FF; 18 = DK/DS; 19 = DK/FF.

100 FSW = weight of 100 fresh seeds; DK/DS = ratio of dry kernel weight to dry seed weight; 100 DSW = weight of 100 dry seeds; DS/FF = ratio of dry seed weight to fresh fruit weight.

\*, \*\* indicated significant differences at  $P < 0.05$  and  $0.01$ , respectively.

(CL53, CL40, and CL4) are recommended in a ratio of approximately 1:1:1, accounting for 90% to 100% of the total, whereas the two recommended cultivars (CL3 and CL18) are recommended in a ratio of 1:1, accounting for 0% to 10% of the total. Based on the research findings, the configuration ratios of the main and recommended cultivars can be optimized for different regions to enhance productivity and adaptability. The following adjustments are proposed. In YX, CL18 can replace CL40 as a main cultivar. In PY, CL3 should be introduced as a main cultivar, whereas the proportions of CL53 and CL40 should be appropriately reduced. In DX, CL3 can replace CL53 as a main cultivar. In YS, CL18 should be added as a main cultivar, whereas the proportions of CL40 and CL4 should be reduced. In ZX, the proportion of CL18 should be increased. In JS, CL18 should be introduced as a main cultivar, whereas the proportions of CL53 and CL4 should be reduced. In WA, the proportion of CL3 should be increased. In SY, CL3 should be added as a main cultivar, whereas the proportion of CL4 should be reduced. In YD, CL18 should be introduced as a main cultivar, whereas the proportions of CL40 and CL4 should be reduced. In XF, CL3 can replace CL40 as a main cultivar. The sum of the comprehensive scores for the five varieties and 10 areas was calculated. A comprehensive ranking of the fruit traits of different varieties or areas was obtained (Table 10). The comprehensive ranking of fruit traits of the five varieties was: CL53, CL4, CL40, CL18, and CL3. The comprehensive ranking of fruit traits of 10 regions was PY, YX, YS, YD, WA, ZX, XF, SY, DX, and JS, in order.

## Discussion

In 2022, the National Forestry and Grassland Administration released the *Catalogue of the Nationwide Main and Recommended Oil Camellia Cultivars*, which refined and standardized the original 120 cultivars and identified 16 primary cultivars and 65 regionally recommended cultivars (Xu et al. 2023). Of these, CL53, CL4, and CL40 were designated as main promoted cultivars, whereas CL18 and CL3 were classified as regionally recommended. However, the performance of these cultivars in actual production and application has not met expectations (Chen et al. 2024; Ji et al. 2024; Zeng and Endo 2019). To understand their regional adaptability, it was necessary to analyze the fruit traits of these cultivars in different geographical locations.

Fruit yield is a critical economic trait and a primary evaluation metric in oil camellia production. However, yield per tree and total yield can vary substantially depending on factors such as tree age, environmental conditions, and cultivation practices (Bertola et al. 2021; Chen et al. 2023; Wang et al. 2023). Therefore, evaluating the regional performance of oil camellia cultivars by comparing fruit traits is a viable approach. One study analyzed the fruit traits of 10 ‘Changlin’ series oil camellia cultivars across three experimental

Table 8. Load coefficients and contribution ratios of principal components in fruit traits.

| Principal components          | $f_1$  | $f_2$  | $f_3$  |
|-------------------------------|--------|--------|--------|
| Eigenvalue                    | 7.483  | 2.299  | 1.108  |
| Contribution ratio            | 57.56% | 17.69% | 8.52%  |
| Cumulative contribution ratio | 57.56% | 75.25% | 83.77% |
| Fruit height                  | 0.827  | -0.337 | -0.075 |
| Narrow diameter               | 0.935  | 0.094  | -0.059 |
| Wide diameter                 | 0.931  | -0.072 | -0.093 |
| Fruit weight                  | 0.976  | 0.016  | -0.139 |
| Pericarp weight               | 0.794  | -0.255 | -0.335 |
| Seed weight                   | 0.942  | 0.230  | 0.043  |
| Seed coat weight              | 0.834  | 0.324  | 0.325  |
| Seed kernel weight            | 0.950  | 0.150  | -0.079 |
| SCMC                          | 0.387  | -0.314 | 0.803  |
| 100 FSW                       | 0.505  | -0.667 | 0.038  |
| 100 DSW                       | 0.676  | -0.205 | 0.050  |
| DS/FF                         | 0.221  | 0.817  | 0.356  |
| DK/FF                         | 0.282  | 0.819  | -0.264 |

100 FSW = weight of 100 fresh seeds; DK/DS = ratio of dry kernel weight to dry seed weight; DK/FF = ratio of dry kernel weight to fresh fruit weight; 100 DSW = weight of 100 dry seeds; DS/FF = ratio of dry seed weight to fresh fruit weight.

fields in Zhejiang and Jiangxi provinces (Jiang et al. 2016). Only the moisture content of fresh seeds and the ratio of dry seeds to fresh fruit were markedly different among regions. In the current study, fruit characteristics exhibited substantial regional variation, even within the same cultivar. Additionally, that study focused on three distinct regions (Jiang et al. 2016), whereas our analysis included 10 regions. The increased sample size in our study likely contributed to the detection of these differences.

Another study analyzed 13 indicators of tree growth, fruit morphology, yield, and economic traits of five 'Changlin' series oil camellia cultivars from 13 regions of Jiangxi Province (Cheng et al. 2024). Cultivars CL3, CL4, and CL40 had similar fruit morphological traits, which concurred with some of our conclusions. However, our findings indicated

that, apart from the narrow/wide diameters and fruit shape index of CL40 and CL18 being similar among regions, there were marked differences in other fruit traits. These discrepancies among studies may be attributed to several factors. First, their investigation areas were concentrated in the northeastern and central regions of Jiangxi Province, and only one region was surveyed in southern Jiangxi, which is the main production area of the Jiangxi oil camellia industry. Second, there was limited overlap between our sampling sites and those of the aforementioned studies, which could contribute to discrepancies in the results. Additionally, variations in management patterns across different bases may also lead to differences in fruit traits.

Research of oil camellia fruit morphology has focused on two approaches: the height

from the fruit stem to the apex (fruit height) and the nearly circular transverse diameter (fruit diameter) (Lin et al. 2022; Lu et al. 2020; Sheng et al. 2023). In the current study, both the narrow and wide transverse diameters of the fruit were measured. CL3 had the largest narrow/wide diameters, whereas CL40 had the smallest dimensions and the most rounded transverse shape. During the process of oil camellia fruit harvesting, seeds simultaneously developed in all three ovules within the locules in CL40. In contrast, CL3 has four locules, and seeds in locules one to three frequently failed to develop. This may explain the differences in narrow/wide diameter characteristics among different camellia cultivars.

Traditionally, CL18 has been considered an orange-shaped fruit. However, our measurements indicated that the fruit shape index of CL18 was 0.94 to 1.02 across the five cultivars. According to the classification system proposed by Peng et al. (2007), CL18 should be categorized as a spherical fruit (0.89–1.07), whereas the other four cultivars, with fruit shape indices of 1.07 to 1.25, should be classified as oval.

One study analyzed the main economic traits of 19 camellia cultivars in Anhui Province and found that CL53 ranked highest in comprehensive evaluation quality in the Changlin series, whereas CL3 had the highest seeds yield (fresh seeds/fresh fruit) and dry seeds yield (dry seeds/fresh fruit) (Ji et al. 2024). Another study investigated the economic traits of six Changlin oil camellia cultivars in central Fujian Province and reported that CL53 had the highest fruit weight, fruit size, and fresh seeds-to-fresh fruit weight ratio, whereas CL3 had the highest dry seed yield (Chen 2023). Another study conducted an analysis of fruit traits for eight Changlin

Table 9. Main component scores and rankings the sum of the comprehensive scores for the five cultivars and 10 areas was calculated. A comprehensive ranking of the fruit traits of different cultivars or areas was obtained (see Table 10).

| Cultivar | Area | $f_z$ | $f_1$ | $f_2$  | $f_3$  | Ranking | Cultivar | Area | $f_z$  | $f_1$  | $f_2$  | $f_3$  | Ranking |
|----------|------|-------|-------|--------|--------|---------|----------|------|--------|--------|--------|--------|---------|
| CL53     | YX   | 5.215 | 7.358 | 1.808  | -2.183 | 1       | CL3      | WA   | 0.306  | 0.538  | 0.397  | -1.454 | 26      |
| CL53     | YS   | 3.299 | 4.573 | 0.481  | 0.537  | 2       | CL53     | PY   | 0.305  | 0.022  | 1.319  | 0.114  | 27      |
| CL4      | YX   | 3.030 | 4.997 | -1.496 | -0.863 | 3       | CL4      | XF   | 0.227  | 0.677  | -1.339 | 0.436  | 28      |
| CL3      | PY   | 2.619 | 4.078 | -0.688 | -0.374 | 4       | CL53     | XF   | 0.053  | 0.704  | -2.010 | -0.069 | 29      |
| CL18     | YS   | 2.314 | 3.385 | -0.462 | 0.843  | 5       | CL18     | ZX   | -0.038 | 0.910  | -2.666 | -0.990 | 30      |
| CL53     | ZX   | 2.297 | 2.969 | 1.810  | -1.237 | 6       | CL40     | SY   | -0.300 | -1.137 | 1.688  | 1.230  | 31      |
| CL4      | WA   | 2.212 | 2.111 | 3.612  | -0.004 | 7       | CL18     | PY   | -0.335 | -0.711 | 1.154  | -0.882 | 32      |
| CL18     | YD   | 1.962 | 3.169 | -0.563 | -0.953 | 8       | CL40     | WA   | -0.598 | -1.287 | 0.714  | 1.331  | 33      |
| CL3      | SY   | 1.625 | 2.561 | -0.441 | -0.412 | 9       | CL40     | ZX   | -0.670 | -1.600 | 1.951  | 0.171  | 34      |
| CL40     | PY   | 1.515 | 1.323 | 2.352  | 1.080  | 10      | CL53     | SY   | -0.672 | -1.268 | 0.518  | 0.887  | 35      |
| CL40     | DX   | 1.041 | 1.520 | -0.424 | 0.844  | 11      | CL3      | YS   | -0.937 | -2.196 | 2.338  | 0.769  | 36      |
| CL18     | YX   | 1.001 | 1.872 | -1.627 | 0.571  | 12      | CL18     | XF   | -1.023 | -1.391 | 0.188  | -1.055 | 37      |
| CL53     | WA   | 0.979 | 0.952 | 1.344  | 0.407  | 13      | CL18     | WA   | -1.696 | -1.469 | -2.677 | -1.197 | 38      |
| CL53     | YD   | 0.949 | 1.208 | 0.525  | 0.083  | 14      | CL4      | SY   | -1.756 | -2.277 | -0.460 | -0.929 | 39      |
| CL40     | JS   | 0.861 | 1.618 | -1.276 | 0.180  | 15      | CL4      | JS   | -1.852 | -2.449 | -0.824 | 0.052  | 40      |
| CL3      | XF   | 0.798 | 1.686 | -2.306 | 1.240  | 16      | CL18     | SY   | -1.871 | -1.976 | -2.849 | 0.867  | 41      |
| CL4      | YS   | 0.743 | 0.335 | 2.175  | 0.524  | 17      | CL53     | JS   | -2.139 | -2.804 | 0.224  | -2.548 | 42      |
| CL18     | JS   | 0.725 | 0.686 | 1.602  | -0.829 | 18      | CL40     | YX   | -2.216 | -2.831 | -1.628 | 0.717  | 43      |
| CL4      | ZX   | 0.684 | 1.067 | -0.344 | 0.225  | 19      | CL3      | ZX   | -2.235 | -3.389 | -0.570 | 2.101  | 44      |
| CL40     | YS   | 0.613 | 0.494 | 0.237  | 2.194  | 20      | CL3      | YD   | -2.380 | -3.168 | -0.424 | -1.115 | 45      |
| CL4      | PY   | 0.602 | 0.964 | -0.494 | 0.432  | 21      | CL40     | XF   | -2.672 | -4.629 | 1.803  | 1.257  | 46      |
| CL40     | YD   | 0.521 | 0.980 | -0.949 | 0.477  | 22      | CL3      | YX   | -2.917 | -3.979 | -1.165 | 0.617  | 47      |
| CL4      | DX   | 0.465 | 0.366 | 0.546  | 0.969  | 23      | CL18     | DX   | -3.482 | -5.142 | 0.720  | -0.983 | 48      |
| CL4      | YD   | 0.392 | 0.118 | 1.307  | 0.342  | 24      | CL53     | DX   | -3.801 | -5.149 | -0.788 | -0.950 | 49      |
| CL3      | DX   | 0.345 | 1.415 | -2.966 | -0.016 | 25      | CL3      | JS   | -4.107 | -5.806 | 0.623  | -2.451 | 50      |

The comprehensive ranking of fruit traits of the five cultivars was as follows: CL53, CL4, CL40, CL18, and CL3. The comprehensive ranking of fruit traits of 10 regions was as follows: PY, YX, YS, YD, WA, ZX, XF, SY, DX, and JS.

Table 10. Comprehensive score and ranking of fruit traits of cultivars and areas.

| Cultivar | $\Sigma fz$ | Ranking | Regions | $\Sigma fz$ | Ranking |
|----------|-------------|---------|---------|-------------|---------|
| CL53     | 6.485       | 1       | YX      | 4.113       | 2       |
|          |             |         | PY      | 4.706       | 1       |
| CL40     | -1.905      | 3       | DX      | -5.431      | 9       |
|          |             |         | YS      | 3.682       | 3       |
| CL18     | -2.443      | 4       | ZX      | 0.037       | 6       |
|          |             |         | JS      | -6.512      | 10      |
| CL4      | 4.747       | 2       | WA      | 1.203       | 5       |
|          |             |         | SY      | -2.974      | 8       |
| CL3      | -6.884      | 5       | YD      | 1.444       | 4       |
|          |             |         | XF      | -2.618      | 7       |

series oil camellia cultivars at experimental sites in Guangshan County, Xin County in Henan Province, and Jinzhai County in Anhui Province, and the results indicated that CL53 exhibited the best overall performance, with the highest kernel content based on dry seed weight, and its seed yield per fresh fruit was second only to that of CL3 (Yang et al. 2022). In the current study, CL53 exhibited the largest fruit morphology and weight indices. CL3 had the highest ratios of fresh seeds to fresh weight and dry seeds to fresh fruit weight, whereas CL18 had the highest ratio of kernel to dry seed weight. Although CL3 had the lowest average ratio of pericarp to fruit weight, CL53 had a lower ratio of pericarp to fruit than CL3 in some regions. The weight ratios of fresh kernels to fresh seeds and dry kernels to dry seeds were substantially higher in CL18 than in CL3, resulting in CL18 having the highest ratio of dry kernels to fresh fruit weight. The studies by Ji et al. and Chen et al. were restricted to a single sampling site. In the current study, the dry seeds extraction rate of fresh fruit for CL3 was higher than that for CL18 in certain regions. This observation suggests that the performance of the same cultivar may vary across regions.

The oil content of oil camellia fruit increases considerably as the fruit approaches maturity (Chen et al. 2006), whereas the moisture content of the seeds gradually decreases during ripening (Li et al. 2014). During the development of oil camellia fruit, the moisture content of the seed kernel decreases and the oil content increases (Lin et al. 2018). A study of the seed oil contents of five Changlin oil camellia cultivars in Jiangxi Province found that the average seeds oil contents, ranked from highest to lowest, were in CL18, CL4, CL40, CL3, and CL53 (Jiang et al. 2016). With the exception of CL18, this ranking was in agreement with the observed order of seed kernel moisture content, ranging from low to high, in the current study. Tian et al. (2023) investigated CL53, CL40, CL4, and CL3 and found that the kernel and fresh fruit oil contents of different oil camellia cultivars under various pollination combinations varied considerably. Except for CL3 and CL18, the rankings of kernel and fresh fruit oil content for the four Changlin series oil camellia cultivars under natural pollination conditions were consistent with the rankings of the dry seed kernel rate and fresh fruit dry kernel rate reported in our study.

Because oil camellia is derived from the seed kernel, the DF/FF is a key metric for evaluating the oil production efficiency of a cultivar. These results indicate that DK/FF can be used as an important index to evaluate fruit maturity and oil accumulation and provides valuable insights for determining the optimal harvest time. This also explains why CL18 and CL3 are only listed as regionally recommended cultivars because they exhibit substantial variability in performance across different regions. Our research further demonstrates that fruit traits of the same cultivar can vary substantially across different regions, thus highlighting the importance of testing the regional performance of oil camellia cultivars before large-scale cultivation.

This study provides optimized cultivar configurations for different regions, thereby offering valuable references for the selection of oil camellia cultivars tailored to specific geographical conditions. By optimizing the cultivar configuration in each region, it is possible to improve overall productivity and economic efficiency of *C. oleifera* cultivation in Jiangxi Province. In this study, the cultivar configuration adjustments were based on regional performance evaluations of the fruit traits. To more precisely define the cultivar selection and configuration strategies for oil camellia oil planting regions in Jiangxi Province in the future, systematic research of various factors, including yield performance and stability of different cultivars, pollination compatibility among cultivars, and local management capabilities, must be conducted.

#### Data availability

Data are available upon request. Raw data can be made available by e-mailing yanc01@163.com.

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