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# Effects of Different Pollen Pollination on Comprehensive Quality of 'Cuiguan' Pear at Harvest Date and Cold Storage Period

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**Abstract** This study was about the effect of different pollen pollination on fruit quality of 'Cuiguan' pear at harvest date and cold storage period. At Songjiang District in Shanghai, China, the main cultivated 'Cuiguan' pear was hand pollinated with 6 pollen treatments (i.e.,'Qingxiang' pear, 'Zaoshengxinshui' pear, 'Housui' pear, 'Wohwang' pear, 'Huanghua' pear, and mixed varieties pear). Morphological parameters of fruit (fruit shape index, weight, seed number, and skin color) and quality parameters (soluble solids content, titratable acid content, firmness with peel and firmness without peel) were investigated at harvest time and during cold storage to identify the different pollens pollination effect. 'Cuiguan' pear fruits obtained from pollination with 'Huanghua' pear and 'Wohwang' pear recorded good appearance parameters (fruit shape index, weight, and skin color) and fresh quality (soluble solids content, titratable acid content, and palate). Among the 'Cuiguan' pear fruits with 6 pollen treatments, 'Huanghua' resulted in the largest fruits with the highest soluble solids and titratable acid contents, and 'Wohwang' resulted in the best cold storage quality with the highest soluble solids and titratable acid contents. This study provided a basis for the selection of pollinating pear varieties and quality improvement of 'Cuiguan'pear in Shanghai.

**Keywords** 'Cuiguan' pear; Different pollens; Pollination effect; Quality; Cold storage

Most pear varieties exhibit pollen self-incompatibility, making cross-pollination crucial for pear production. When different pollens are used to pollinate flowers of the same pear variety, variations arise in seed and fruit quality. To improve pear fruit quality, it's essential to select appropriate parental varieties through experiments involving cross-pollination using different pollens. Existing studies have reported on the effects of different pollens on 'Jingbai' pear (Sha et al., 2006), 'Kuerlexiangli' pear (Xie et al., 2013; Mansur et al., 2019), 'Nanguo' pear (Wang et al., 2009), 'Nanhong' pear (Wang et al., 2018), 'Dangshan' pear (Zhang, 2011; Zhang, 2013; Li, 2018), 'Cuiguan' pear (Liu et al., 2015; Lou, 2021), 'Yali' pear (Zhang et al., 2020; Liu et al., 2022), 'Zaosu' pear (Wang et al., 2013), and 'Chuxialǜ' pear (Zheng et al., 2019, Chinese Southern Fruit Trees, 48(2): 102-109) concerning different pollen pollination. However, limited research exists regarding the effects of different pollen pollination on the harvesting and post-harvest quality changes of the early-maturing pear variety 'Cuiguan' in the Shanghai region.

The 'Cuiguan' pear belongs to the *P. pyrifolia* Nakai system and is a crossbreed between 'Xingshui' and ('Hangqing' × 'Xinshiji') (Shi and Guo, 1999). Cultivated by the Horticultural Research Institute of Zhejiang Academy of Agricultural Sciences, the 'Cuiguan' pear is one of the largest early-maturing pear varieties cultivated nationwide and is the most extensively cultivated variety in Shanghai. This study selected six pear pollen types for pollination of the 'Cuiguan' pear to investigate the impact of different pollens on the harvest and post-harvest comprehensive quality of 'Cuiguan' pears. The aim is to select appropriate pollination tree varieties suitable for the production of 'Cuiguan' pears in the Shanghai region, providing a theoretical basis for improving the fruit quality of 'Cuiguan' pears.

## 1 Results and Analysis

### 1.1 The visual quality of the 'Cuiguan' pear in the six pollination treatments

Based on the a* values (Table 1), apart from the 'Fengshui' pear pollination resulting in brown fruit skin, the skin color of other treatments appeared as light green. There was a significant difference in the a* values between the 'Fengshui' pear pollination and 'Huanghua' pear pollination compared to commercial pear pollen pollination.

Table 1 Fresh exterior quality of pear with 6 pollination treatments

| Code name | a* | b* | L* | Fruit shape index |
|---|---|---|---|---|
| CL1 | -14.71$^{Ccd}$ | 45.867$^{Aa}$ | 75.738$^{ABab}$ | 0.965$^{ABab}$ |
| CL2 | -15.099$^{Cd}$ | 45.46$^{Aa}$ | 73.554$^{Bbc}$ | 0.98$^{Aa}$ |
| CL3 | 0.132$^{Aa}$ | 42.533$^{Bb}$ | 69.123$^{Cd}$ | 0.891$^{Bc}$ |
| CL4 | -9.244$^{BCbc}$ | 45.621$^{Aa}$ | 77.967$^{Aa}$ | 0.94$^{ABabc}$ |
| CL5 | -6.414$^{ABb}$ | 44.321$^{ABab}$ | 72.285$^{BCc}$ | 0.934$^{ABabc}$ |
| CK | -13.274$^{BCcd}$ | 45.918$^{Aa}$ | 73.915$^{Bbc}$ | 0.916$^{ABbc}$ |

Note: The data with different capital letters in same column show extremely significant difference; the data with different little letters in same column show significant difference

According to the b* values, all six pollination treatments displayed yellow fruit color, with only the 'Fengshui' pear pollination significantly different from the commercial pear pollen pollination.

Based on the L* values, all treatments had positive values. The 'Fengshui' pear pollination exhibited the lowest L* value, indicating the darkest fruit skin, significantly different from the commercial pear pollen pollination. On the other hand, 'Yuanhuang' pear pollination showed the highest L* value, indicating the brightest skin color. Both 'Fengshui' and 'Yuanhuang' pear pollinations significantly differed from the commercial pear pollen pollination.

The 'Zaoshengxinshui' pear pollination demonstrated the highest fruit shape index, significantly different from the commercial pear pollen pollination. Conversely, the 'Fengshui' pear pollination displayed the lowest fruit shape index, resembling the shape of the 'Fengshui' pear, being oblate. The fruit shape index of 'Fengshui' pear pollination significantly differed from the commercial pear pollen pollination. Both 'Yuanhuang' and 'Huanghua' pear pollinations exhibited higher fruit shape indices than the commercial pear pollen pollination, but the difference was not significant.

The a* values of all five pollination treatments were higher than that of the commercial pear pollen pollination. The 'Fengshui' and 'Huanghua' pear pollinations displayed the lightest green color, significantly different from the commercial pear pollen pollination. The b* value of the 'Fengshui' pear pollination significantly differed from the commercial pear pollen pollination. Except for the 'Fengshui' pear pollination, the fruit skin of the remaining pollination treatments showed a light yellow-green color. Both 'Fengshui' and 'Yuanhuang' pear pollinations' L* values significantly differed from the commercial pear pollen pollination. The 'Yuanhuang' pear pollination resulted in the brightest skin color of the fruit (Figure 1).

Except for 'Fengshui' pear pollination, the individual fruit weight of the 'Cuiguan' pear in other pollination treatments was higher than that of the commercial pear pollen pollination. The single fruit weight of 'Qingxiang' pear pollination, 'Zaoshengxinshui' pear pollination, 'Yuanhuang' pear pollination, and 'Huanghua' pear pollination significantly differed from the commercial pear pollen pollination. Comparatively, the shriveled seed number of 'Yuanhuang' pear pollination significantly differed from the commercial pear pollen pollination. The plump seed number of 'Fengshui' pear pollination and 'Yuanhuang' pear pollination significantly differed from the commercial pear pollen pollination. Except for 'Zaoshengxinshui' pear pollination and 'Fengshui' pear pollination, the fruit setting rates of 'Cuiguan' pear in other pollination treatments met production requirements (Table 2).


Figure 1 Influence of pollinators on pear size and peel color

Table 2 Fresh quality of pear with 6 pollination treatments

| Code name | Single fruit weight | Number of dry seeds | Number of filled seeds | Maturing rate (%) |
|---|---|---|---|---|
| CL1 | $351.665^{Aa}$ | $4.2^{ABabc}$ | $6.3^{ABb}$ | >50.0 |
| CL2 | $336.471^{Aba}$ | $6^{Aa}$ | $3.6^{BCc}$ | 17.4 |
| CL3 | $234.588^{Ca}$ | $3^{ABbc}$ | $1.7^{Cc}$ | 11.0 |
| CL4 | $356.41^{Aa}$ | $1.9^{Bc}$ | $8.4^{Aa}$ | >50.0 |
| CL5 | $369.966^{Aa}$ | $4.2^{ABabc}$ | $6.0^{ABb}$ | >50.0 |
| CK | $271.313^{BCb}$ | $4.6^{ABab}$ | $5.8^{ABb}$ | >50.0 |

Note: The data with different capital letters in same column show extremely significant difference; the data with different little letters in same column show significant difference

### 1.2 The fruit quality of the 'Cuiguan' pear in the six pollination treatments

The soluble solids content of 'Zaoshengxinshui,' 'Yuanhuang,' and 'Huanghua' pear pollination treatments were higher than those of the commercial pear pollen pollination, although the difference was not significant. The titratable acidity of each pollination treatment was higher than that of the commercial pear pollen pollination, with a significant difference.

The skin hardness of 'Qingxiang', 'Zaoshengxinshui', and 'Fengshui' pear pollination fruits was higher than that of the commercial pear pollen pollination, yet the difference was not significant. However, the flesh hardness of 'Fengshui' pear pollination fruits was higher than that of the commercial pear pollen pollination, although the difference was not significant (Table 3).

### 1.3 Changes in external quality of 'Cuiguan' pear fruit during cold storage

Based on the variations in a*, b*, and L* indices of 'Cuiguan' pear fruits after five months of cold storage with six pollen pollination treatments (Table 4; Figure 2; Figure 3; Figure 4), all 'Cuiguan' pear fruit surfaces exhibited similar brightness, appearing as a light yellowish-green. While all treatments displayed a light yellowish-green

color, the b* values of 'Qingxiang', 'Yuanhuang', and 'Huanghua' pear pollination were higher than those of the commercial pear pollen pollination, with 'Huanghua' pear pollination showing a significantly different b* value compared to the commercial pear pollen pollination.

Table 3 Fresh interior quality of pears with 6 pollination treatments

| Code name | Content of soluble solids (%) | Content of titratable acid (%) | Fruit firmness with peel (kg/cm$^2$) | Fruit firmness without peel (kg/cm$^2$) |
|---|---|---|---|---|
| CL1 | 12.28$^{BCb}$ | 0.157$^{Aa}$ | 5.311$^{Aa}$ | 2.539$^{ABa}$ |
| CL2 | 12.79$^{ABCab}$ | 0.144$^{Bbc}$ | 5.365 $^{Aa}$ | 2.477$^{ABa}$ |
| CL3 | 12.17$^{Cb}$ | 0.149$^{ABb}$ | 5.366 $^{Aa}$ | 2.824$^{Aa}$ |
| CL4 | 13.23$^{Aa}$ | 0.14$^{BCc}$ | 4.087 $^{Aa}$ | 1.874$^{Bb}$ |
| CL5 | 13.18$^{ABa}$ | 0.156$^{Aa}$ | 4.652 $^{Aa}$ | 2.41$^{ABa}$ |
| CK | 12.61$^{ABCab}$ | 0.133$^{Cd}$ | 5.144 $^{Aa}$ | 2.539 $^{ABa}$ |

Note: The data with different capital letters in same column show extremely significant difference; the data with different little letters in same column show significant difference

Table 4 Exterior quality of pears with different pollination treatments after 5 months of cold storage

| Code name | a* | b* | L* |
|---|---|---|---|
| CL1 | -6.765$^{Aa}$ | 39.41$^{ABb}$ | 77.794$^{Aa}$ |
| CL2 | / | / | / |
| CL3 | / | / | / |
| CL4 | -6.554$^{Aa}$ | 41.304$^{ABab}$ | 76.689 $^{Aa}$ |
| CL5 | -7.679$^{Aa}$ | 42.792$^{Aa}$ | 78.878 $^{Aa}$ |
| CK | -8.763$^{Aa}$ | 38.471$^{Bb}$ | 78.388 $^{Aa}$ |

Note: The data with different capital letters in same column show extremely significant difference; the data with different little letters in same column show significant difference

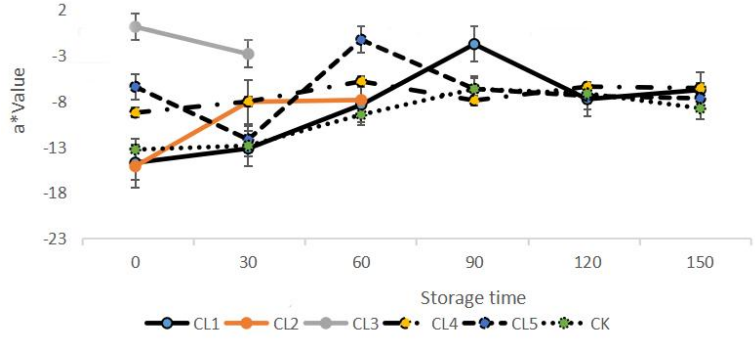


Figure 2 Changes in a* values of ‘Cuiguan’ pears with 6 pollination treatments during 5 months of cold storage

### 1.4 Changes in internal quality of 'Cuiguan' pear fruit with six pollination treatments during cold storage

The variation in soluble solids content of 'Cuiguan' pears with six pollination treatments during cold storage displayed a slow increase followed by a slow decline, with differing peak times (Figure 5). After five months of cold storage, the soluble solids content of 'Yuanhuang' and 'Huanghua' pear pollination treatments was higher than that of commercial pear pollen pollination. Compared to commercial pear pollen pollination, the 'Yuanhuang' pear pollination showed significantly higher soluble solids content than other pollination types. Sensory tests also demonstrated similar outcomes, indicating that after five months of cold storage, 'Cuiguan' pears from 'Yuanhuang' pear pollination tasted notably sweeter (Table 5; Table 6).

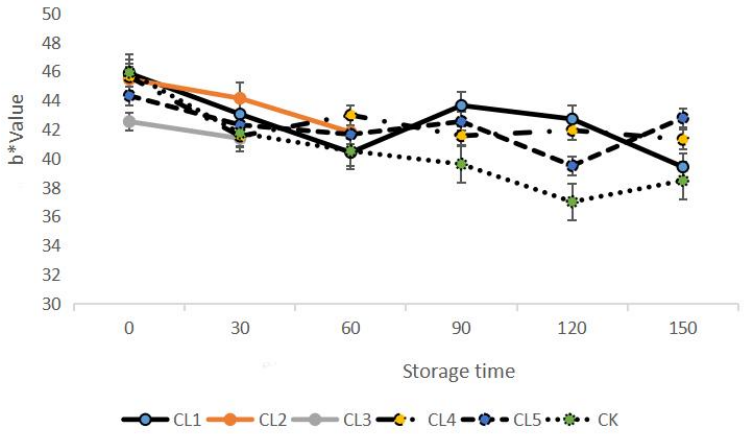


Figure 3 Changes in b* values of ‘Cuiguan’ pears with 6 pollination treatments during 5 months of cold storage

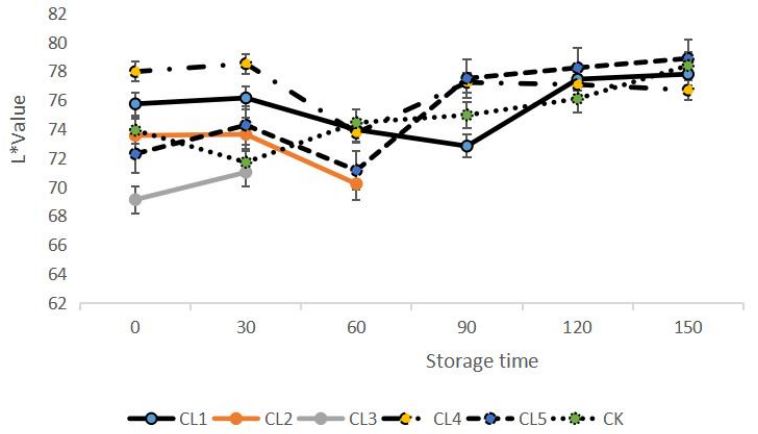


Figure 4 Changes in L* values of ‘Cuiguan’ pears with 6 pollination treatments during 5 months of cold storage

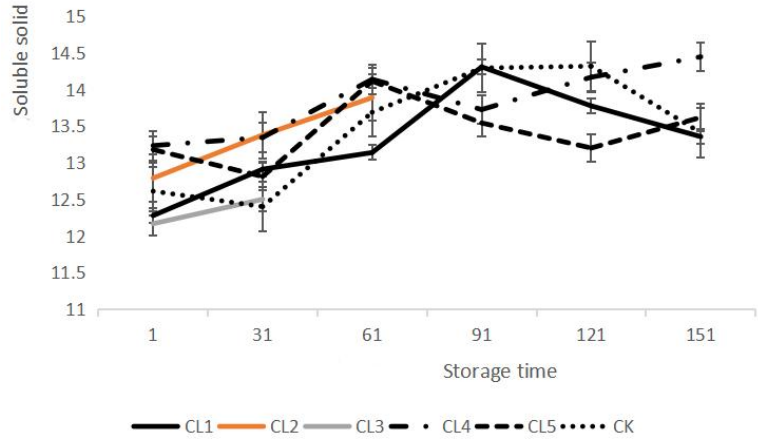


Figure 5 Soluble solids content (Brix %) changes in ‘Cuiguan’ pears with 6 pollination treatments during 5 months of cold storage

The trends in skin hardness and flesh hardness of 'Cuiguan' pear fruit under six pollination treatments during cold storage were similar. Except for 'Fengshui' pear pollination, the fruit hardness of 'Cuiguan' pears from other pollination combinations showed a slow decline followed by an increase, and then a subsequent slow decline during the five-month cold storage period. After five months of cold storage, the titratable acid content of 'Yuanhuang' pear pollination was the highest among the pollination treatments, exhibiting a significant difference compared to commercial pear pollen pollination (Figure 6).

Table 5 Fruit Soluble solids content (Brix %) with 6 pollination treatments during 5 months of cold storage

| Code name | Aug., 2019 | Sep., 2019 | Oct., 2019 | Nov., 2019 | Dec., 2019 | Jan., 2020 |
|---|---|---|---|---|---|---|
| CL1 | $12.28^{BCb}$ | $12.91^{Aab}$ | $13.14^{Ab}$ | $14.31^{Aa}$ | $13.78^{ABab}$ | $13.36^{Bb}$ |
| CL2 | $12.79^{ABCab}$ | $13.38^{Aa}$ | $13.89^{Aab}$ | - | - | - |
| CL3 | $12.17^{Cb}$ | $12.5^{Ab}$ | - | - | - | - |
| CL4 | $13.23^{Aa}$ | $13.34^{Aa}$ | $14.14^{Aa}$ | $13.73^{Aab}$ | $14.17^{Aa}$ | $14.45^{Aa}$ |
| CL5 | $13.18^{ABa}$ | $12.81^{Aab}$ | $14.11^{Aa}$ | $13.54^{Ab}$ | $13.2^{Bb}$ | $13.62^{ABb}$ |
| CK | $12.61^{ABCab}$ | $12.4^{Ab}$ | $13.69^{Aab}$ | $14.29^{Aa}$ | $14.32^{Aa}$ | $13.41^{Bb}$ |

Table 6 Fruit palate with 6 pollination treatments during 5 months of cold storage

| Code name | Aug., 2019 | Sep., 2019 | Oct., 2019 | Nov., 2019 | Dec., 2019 | Jan., 2020 |
|---|---|---|---|---|---|---|
| CL1 | Well watered | Well watered | Well watered | Well watered | Watered | Watered |
| CL2 | Well watered | Well watered | Watered | - | - | - |
| CL3 | Watered | - | - | - | - | - |
| CL4 | Well watered | Well watered | Well watered | Well watered | Watered | Watered |
| CL5 | Well watered | Well watered | Well watered | Well watered | Watered | Watered |
| CK | Well watered | Well watered | Well watered | Well watered | Watered | Watered |

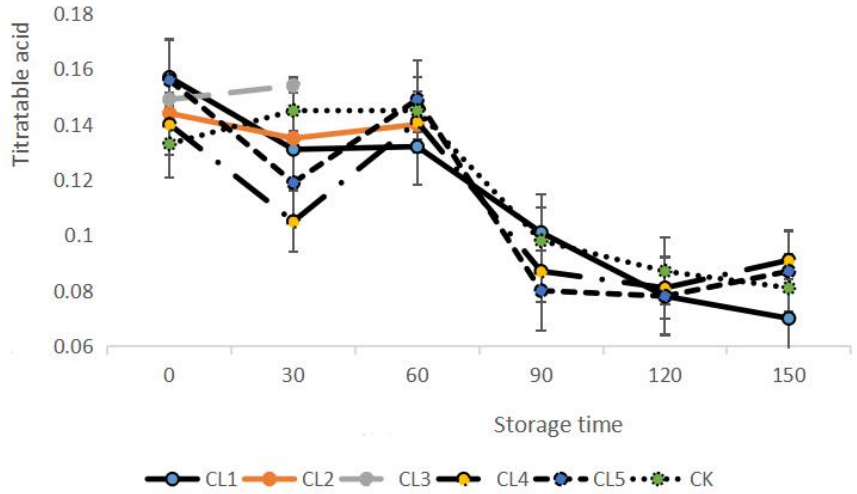


Figure 6 Titratable acid content (%) changes in ‘Cuiguan’ pears with 6 pollination treatments during 5 months of cold storage

After five months of cold storage, the soluble solids and titratable acid content of 'Yuanhuang' and 'Huanghua' pear pollinations were higher compared to commercial pear pollen pollination. The levels of soluble solids and titratable acid content in 'Yuanhuang' pear pollination were significantly higher than those in commercial pear pollen pollination. The fruit hardness, both with skin and without, of 'Qingxiang' pear pollination was higher than that of commercial pear pollen pollination and showed significant differences (Figure 7; Figure 8; Table 7).

## 2 Discussion

The comprehensive quality indicators during harvest show that compared to commercial pear pollen pollination, 'Huanghua' pear pollination treatment for 'Cuiguan' pear had brighter fruit skin color, heavier single fruit weight, higher soluble solids content, and higher titratable acid content. Therefore, 'Huanghua' is an appropriate pollination variety for 'Cuiguan' pear. Compared to commercial pear pollen pollination, 'Yuanhuang' pear pollination resulted in brighter fruit skin color, higher fruit shape index, and heavier single fruit weight, making 'Yuanhuang' a suitable pollination variety for 'Cuiguan' pears.

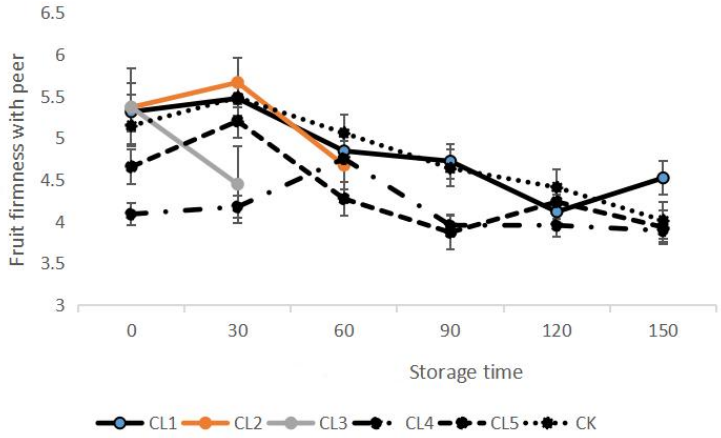


Figure 7 Firmness with peel (kg/cm²) changes in 'Cuiguan' pears with 6 pollination treatments during 5 months of cold storage

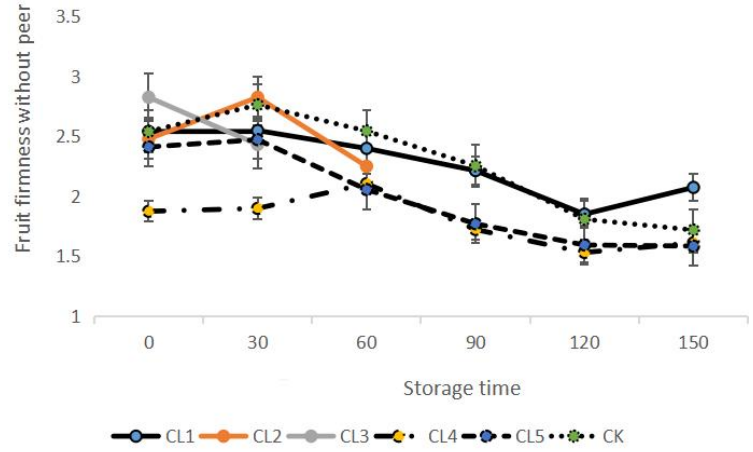


Figure 8 Firmness without peel (kg/cm²) changes in 'Cuiguan' pears with 6 pollination treatments during 5 months of cold storage

Table 7 Interior quality of pears with different pollination treatments after 5 months of cold storage

| Code name | Soluble solids (%) | Content of titratable acid(%) | Fruit firmness with peel (kg/cm$^2$) | Fruit firmness without peel (kg/cm$^2$) |
|---|---|---|---|---|
| CL1 | 13.355$^{Bb}$ | 0.07$^{Bc}$ | 4.52$^{Aa}$ | 2.073$^{Aa}$ |
| CL4 | 14.445$^{Aa}$ | 0.091$^{Aa}$ | 3.889$^{Ab}$ | 1.611$^{Bb}$ |
| CL5 | 13.618$^{ABb}$ | 0.087$^{Aab}$ | 3.93$^{Ab}$ | 1.584$^{Bb}$ |
| CK | 13.409$^{Bb}$ | 0.081$^{Ab}$ | 4.01$^{Aab}$ | 1.718$^{ABb}$ |

Note: The data with different capital letters in same column show extremely significant difference; the data with different little letters in same column show significant difference

The pollen-specific effects of 'Cuiguan' pear were the primary factor affecting the differences in fruit quality after different pollen pollinations. The quality tests during the harvest of 'Cuiguan' pears showed significant pollen-specific effects in fruit skin color and single fruit weight for 'Huanghua' and 'Yuanhuang' pear pollination treatments. This aligns with previous findings on 'Cuiguan' pears using pollen from other varieties in Zhejiang province, where significant pollen-specific effects were observed in color difference index and single fruit weight (Lou, 2021). Pollen-specific effects on single fruit weight were notable in studies on 'Nanguo' pears (Wang et al., 2009), 'Dangshan' pears (Zhang, 2011), and 'Chuxialǜ' (Zheng et al., 2019, South China Fruit Trees, 48(2): 102-109), but not significant in 'Ya' pears (Liu et al., 2022), indicating variations in pollen-specific effects among different pear varieties.

After five months of cold storage, comparative analysis of comprehensive quality indicators of 'Cuiguan' pears indicated that 'Yuanhuang' pear pollination had higher levels of soluble solids, with and without skin hardness, and better taste compared to the commercial pear pollen pollination and other treatments. This suggests that 'Yuanhuang' pears as a pollination tree variety help maintain the quality of 'Cuiguan' pears during cold storage. After five months of cold storage, 'Qingxiang' pears with and without skin hardness were higher than commercial pear pollen pollination, indicating that 'Qingxiang' as a pollination tree variety also contributes to extending the cold storage life of 'Cuiguan' pears. The pollen-specific effects of 'Cuiguan' pears were the main factor affecting differences in fruit quality during the cold storage period. Testing during the cold storage period showed significant pollen-specific effects for 'Huanghua' and 'Yuanhuang' pear pollination in traits like skin and without skin hardness.

Most pear varieties exhibit self-incompatibility, indicating the need for pollination trees in pear production, which is determined by different pear S genes. The pollination incompatibility exists between pear varieties with the same S gene type. The S gene type of 'Cuiguan' pears is S3S5 (Zhang, 2007), different from 'Qingxiang' pears (S gene type S4S7) (Xu, 2013), 'Huanghua' pears (S gene type S1S2) (Zhang et al., 2018), and the mixed pollen of commercial pear pollen pollination (S gene type 'Xueqing' pear S3S16 and 'Xuehua' pear and 'Xuefang' pear S4S16) (Heng et al., 2007). Therefore, the 'Qingxiang' pear pollination, 'Huanghua' pear pollination, and commercial pear pollen pollination treatments exhibit higher fruit setting rates. The S gene types of 'Cuiguan' pears and 'Fengshui' pears are the same (Ishimizu et al., 1999), resulting in a lower fruit setting rate for 'Fengshui' pear pollination. The S gene types of 'Zaoshengxinshui' pears and 'Yuanhuang' pears have not been reported and require identification to clarify the molecular mechanism for the lower fruit setting rate of 'Zaoshengxinshui' pear pollination and the higher fruit setting rate of 'Yuanhuang' pear pollination for 'Cui Guan' pears."

## 3 Materials and Methods

### 3.1 Materials

The materials used in this experiment were pear trees located in the Shanghai Cangqiao Crystal Pear Cooperative Pear Production Base. All trees were 12 years old. Six pollination varieties-'Qingxiang', 'Zaoshengxinshui', 'Fengshui', 'Yuanhuang', 'Huanghua', and commercial pear pollen—were selected for the pollination experiment on 'Cuiguan' pears (Table 8).

Table 8 6 Pear pollinating parents involved in the experiment

| Code name | Pollinating parents(♀ × ♂) |
|---|---|
| CL1 | ‘Cuiguan’ × ‘Qingxiang’ |
| CL2 | ‘Cuiguan’ × ‘Zaoshengxinshui’ |
| CL3 | ‘Cuiguan’ × ‘Housui’ |
| CL4 | ‘Cuiguan’ × ‘Wonhwang’ |
| CL5 | ‘Cuiguan’ × ‘Huanghua’ |
| CK | ‘Cuiguan’ × ‘Mixed varieties’ |

### 3.2 Pollination and fruit handling methods

For each variety-'Qingxiang', 'Zaoshengxinshui', 'Fengshui', 'Yuanhuang', and 'Huanghua'-600 bell-shaped flower buds were collected, and with forceps, petals and stamens were removed to collect anthers. Anthers were spread on sulfuric acid paper (A4 size) and placed in a constant temperature oven at 20 °C for 24 hours. After pollen release, the pollen was collected, packaged, labeled, and stored in a dry silica gel bottle at 4 °C for pollination. Commercial pear pollen was obtained from the market for the commercial pollen pollination.

Twelve 'Cuiguan' pear trees with three main branches and consistent growth vigor were selected for the experiment. On March 25, 2019, flower buds between 1 and 1.5 meters above the ground were sampled for the experiment. Only one flower bud per inflorescence (the 3rd, 4th, or 5th position) was pollinated, maintaining a distance of about 20~25 cm between adjacent flower buds, and the rest were thinned out. Pollinated flower buds were covered with marked wax paper bags to prevent contamination by other pollen. After 40 days, standard fruit

bags were used to cover the young fruits. The management of these 12 experimental pear trees followed the practices of the base orchard.

On July 31, 2019, during the optimal harvest period, 'Cuiguan' pears from the bagged fruits on the 12 experimental trees were harvested and placed on a cement platform in the warehouse at room temperature for 24 hours to eliminate field heat. The fruits were then stored in a cold storage room at 0 °C. Each month, 10~12 fruits from each of the six pollination treatments were randomly sampled from the cold storage room for comprehensive quality testing.

### 3.3 Quality determination methods

The Institute of Fruit Trees at the Shanghai Academy of Agricultural Sciences assessed the fruit quality indicators of the six pollination treatments: single fruit weight, soluble solids content, hardness (with and without skin), titratable acidity, fruit shape index, seed count, and fruit skin color.

Single fruit weight was measured using a digital scale, with at least 20 pear fruits measured for each treatment.

Soluble solids content was determined using an ATAGO refractometer. Readings were taken at three equatorial points on each fruit, and the average value represented the soluble solids content. At least 8 pear fruits from each pollination treatment were measured monthly.

Fruit hardness with skin was measured at two equidistant points around the equator using a FAT-1 hardness tester. For measuring skinless fruit hardness (fruit flesh hardness), the skin was removed using a fruit knife, and measurements were taken at two equidistant points around the fruit's equator. 8~12 pear fruits were measured monthly for each pollination treatment.

Titratable acidity was determined using acid-base titration, represented by the equivalent value of malic acid. 8~12 pear fruits from each pollination treatment were tested monthly.

Fruit shape index was measured using a vernier caliper, with at least 20 pear fruits measured for each pollination treatment.

Seed count involved the calculation of intact and shriveled seeds.

Fruit skin color was measured using a Konica Minolta CR-400 automatic colorimeter. Ten fruits were randomly selected from each treatment to determine the color difference on both sides of the fruit (opposite sides of the fruit equator). L* value (brightness; with a minimum of zero representing black, higher values indicating brighter colors), a* value (red-green difference; positive a* values indicate red, negative values indicate green), and b* value (yellow-blue difference; positive b* values indicate yellow, negative values indicate blue) were measured. At least 8 pear fruits were analyzed monthly for each treatment.

### 3.4 Statistical methods of experimental data

The measurement results were statistically analyzed using SAS9.0 software.

## Authors' contributions

ZH and LBC were the experimental designers and executors of this study, responsible for data analysis and the initial draft of the paper. JXT contributed to the data analysis. ZH was the originator and leader of the project, guiding the experimental design, data analysis, and paper writing and revision. All authors read and approved the final manuscript.

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## References

Heng W., Zhang S.L., Zhang Y.Y., Wu J., and Li X.G., 2007, Identification of S-genotypes of twelve pear cultivars by analysis of DNA sequence, Yuanyi Xuebao (Acta Horticulture Sinica), 34(4): 853-858.

Ishimizu T., Inoue K., Shimonaka M., Saito T., Terai O., and Norioka S., 1999, PCR-based method for identifying the S-genotypes of Japanese pear cultivars, Theor. Appl. Genet., 98: 961-967.
https://doi.org/10.1007/s001220051156

Li S.M., 2018, Fruit quality and lignin metabolism of 'Dangshan Su' pear by pollination, Dissertation for Ph.D., Anhui Agricultural University, Supervisor: Lin Y., pp.13-19.

Liu W.J., Zhang Y., Zhang Y.X., and Du G.Q., 2022, Analysis and evaluation of the fruit quality and aroma components of 'Yali' pear (Pyrus bretschneideri Rehd.) pollinated with eighteen pollinizers, Shipin Kexue (Food Science), 43(2): 294-302.

Liu Z.Q., Bao T., and Zheng Y.T., 2015, Effect of different pollination varieties on quality of 'Cuiguan' pear fruit, Beifang Yuanyi (Northern Horticulture), (22): 37-39.

Lou Y.H., 2021, Effects of xenia on fruit quality and sugar accumulation of 'Cuiguan' pear, Thesis for M.S., Zhejiang A & F University, Supervisor: Xu K., pp.22.

Mansur N., Du R.Q., Chen X.Y., Zhou W.Q., Niu Y.Y., Ablah N., and Liao K., 2019, Pollination compatibility compatibility and pollen xenia of Xinjiang pear cultivars with 'Kuerlexiangli' pear, Guoshu Xuebao (Journal of Fruit Science), 36(4): 447-457.

Sha H.F., Zhu Y.D., Gao Q.J., and Zhang W., 2006, Effect of xenia on fruit quality of Jingbaili pear cultivar, Guoshu Xuebao (Journal of Fruit Science), 23(2): 287-289.

Shi Z.B., and Guo X.G., 1999, The breeding of early ripening pear variety Cuiguan and its application, Zhejiang Nongye Xuebao (Acta Agriculturae Zhejiangensis), 11(4): 212-214.

Wang J.Z., Cai Z.M., Sha S.F., Li H.J., Jiang X.Y., and Gu D.J., 2018, Effect of different pollinators on fruiting characteristics of 'Nanhong' pear, Beifang Yuanyi (Northen Horticulture), (8): 69-72.

Wang J.Z., Li J.C., Liu C., Cai Z.M., Sha S.F., Li H.J., and Yu N.W., 2009, Xenia on Nanguoli pear cultivar, Beifang Yuanyi (Northern Horticulture), 7: 106-107.

Wang W., Li H.X., Zhao M.X., Cao S.F., and Sun W.T., 2013, Comparison of pollination effects of seven pollination pear cultivars and Zaosu Pear, Jingjilin Yanjiu (Non-wood Forest Research), (3): 150-153.

Xie H., Gao Q.M., Liu Y.J., Nan X., Zhang W., Li S.Q., and Li J., 2013, Effects of Xenia on fruit quality of korla fragrant pear cultivar, Xibei Nongye Xuebao (Acta Agriculture Boreali- occidentalis Sinica), 22(1): 93-96.

Xu F.F., 2013, Research of the self-incompatibility genotypes (S-genotypes) in pear, Thesis for M.S., Nanjing Agriculture University, Supervisor: Zhang S.L., pp.39.

Zhang A., 2011, Studies on the relationship between endogenous hormones and metaxenia of Dangshansu pear, Thesis for M.S., Anhui Agricultural University, Supervisor: Xu Y.L., pp.24-25.

Zhang N., 2013, The effect of cross pollination on pear quality, stone cell and cDNA-SRAP analysis, Thesis for M.S., Anhui Agricultural University, Supervisor: Cai Y.P., pp.17-18.

Zhang X.L., AiShaJiang M.M.T., Xu Y.T., Deng L., and Wang J.X., 2018, Present advance of S-gene genotype and S-genotype in pear, Xibei Nongye Xuebao( Acta Agriculture Boreali-occidentalis Sinica), 27(8): 1077-1087.

Zhang Y., Liu W.J., Cheng X.H., Du G.Q., and Zhang Y.X., 2020, Effects of pollinizer cultivars on the morphogenesis and development of Yatu and the endogenous hormone content in the base of young fruit of 'Yali'pear (Pyrus bretschneideri Rehd.), Guoshu Xuebao (Journal of Fruit Science), 37(8): 1168-1174.

Zhang Y.Y., 2007, Analysis of genetic relationship and identification of S-genotypes and clone of S-RNase gene in Pyrus, Dissertation for Ph.D., Nanjing Agricultural University., Supervisor: Zhang S.L., pp.66.