

Study on Effect of Different Varieties Configuration upon Yield of Yan Mountain Chestnut

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ABSTRACT

In order to improve the yield and quality of 5 new *Castanea mollissima* varieties “Zipo”, “Zunyu” and traditional Yan Mountain *Castanea mollissima* cultivars “Duanci”, “Yanhong” and “Donglingmingzhu”, we carried out an experiment to study effect from different varieties configuration on yield of Yan Mountain chestnut. The result indicated that: cross-pollination had a significant impact on both fruiting rate and seed-setting rate; cross-pollination improved the nut number in each burr of each variety, in which “Duanci” was the biggest beneficiary, whose number of nut per burr increased from 1.08 to 2.77, 156% higher than that of the self-pollination combination; nut weight showed no significant difference in Xenia Effect; “Zunyu” improved the yield of “Yanhong” most; “Donglingmingzhu” was regarded as the best tree to improve “Zunyu”’s yield; the best variety to improve yield of “Zipo” was “Zunyu”; “Donglingmingzhu” and “Duanci” improved yield of each other most.

Keywords: *Castanea mollissima* Bl; Configuration; Fruiting Rate; Seed-Setting Rate; Number of Nuts per Burr; Nut Weight; Yield

1. Introduction

Chestnut (*Castanea mollissima*) was considered as one of Chinese endemic species and the nutrient-rich nuts have unique flavor and great economic value [1]. Meanwhile, Chinese chestnut is quite competitive in world markets because it has good taste and easily peeled off astringent seed capsule [2]. Yan Mountain chestnut mainly grow in Qianxi, Zunhua, Xinglong, Kuancheng, Qinglong counties, Hebei province and Huairou, Miyun, Pinggu and Changping areas in Beijing. All of the nuts have exquisite shape, delicate meat and are high in sugar content. The nuts are famous for being fried with the trade name “Tianjin Sweet Chestnut” or “JingDong Chestnuts”. Varieties mainly cultivated in Yan Mountain area are Yanghong, YanChang, YanMing, Timazhenzhu, Zipo, Zunyu, Huai Huang, Huaijiu, Zunhuaduanci and so on.

Castanea mollissima is a typical kind of cross-pollination plants and its self-pollination seed-setting rate is very low which only reached 10% to 40% [3]. Many scholars had carried out related researches. Such as Mokay, he has already confirmed that the infertility under self-pollination on some chestnut seedling trees was due to incompatibility between male gametes and female gametes [4]. In addition, the stigma of pistil has strong selectivity on pollen, so affinity between different cultivars combinations are different. The test cross about

different chestnut varieties conducted by Wenbang Fan and other experts showed that fruiting rate in case of self-pollination was much lower as against that of cross-pollination [5]. As a result, fruiting rate and seed-setting rate will ultimately affect yield of chestnut.

The experiment carried out by Kong Dejun indicated that per standard unit the number of nut per burr and nut weight increased, the yield of each tree will be improved respectively by 0.669 and 0.246 standard unit, which showed that these two traits could be considered as two key factors that affect the yield of chestnut [6].

People always paid much attention to production of chestnut [7-9], but disadvantages such as too much seedling trees, mess of mixed species and low yield per unit area still exist in production [10,11]. Therefore, to improve the yield of chestnut is an urgent need to address. In this study, we selected new varieties *Castanea mollissima* cv. “Zipo”, “Zunyu”, which were bred during “The Eleventh Five-year Plan” in China and the traditional Yan Mountain cultivars *Castanea mollissima* cv. “Duanci”, “Yanhong” and “Donglingmingzhu” as research materials to study varieties combination which could promote their yield most. The comprehensive effect of fruiting rate, seed-setting rate, number of nuts per burr and nut weight were the decisive factor to affect the result. The ultimate goal of this experiment is to provide a scientific theoretical

basis to improve the yield of new chestnut orchard.

2. Materials and Methods

2.1. Overview of Test Site and Background

The pollination experiment was carried out in the chestnut breeding base in Zunhua City, Hebei Province which is located at 40°11'50"N latitude and 117°58'30"E longitude. It is in the north of Tangshan City and belongs to warm temperate semi-humid monsoon climate and has four distinct seasons. The annual average sunshine hours is 2608.2 hours, annual average temperature is 10.9°C, and lowest temperature is -25.7°C. Frost-free period reaches 182 days and its precipitation is 724.7 millimeters. This chestnut breeding base was selected as the test site was because Zunhua is one of the main chestnut production bases in north China.

Zunhua Chestnut mainly distributed in northern and western mountains areas along the Great Wall which is rich in gneiss. Weathered gneiss soils which contains large number of iron, managanese, sulfur, boron and other inorganic nutrients, coupled with low temperatures, large temperature difference and abundant rainfall here, make it suitable for growth of chestnut.

Castanea mollissima cv. "Zunhua pagoda 54" has been tested by Chinese Academy of Sciences and the result showed that it contained 10% sugar, 55.07% starch, 6.21% crude protein, 3.3% crude fat, vitamin C 4.5 milligram per 100 gram, vitamin B 10.289 milligram per 100 gram and vitamin E 0.275 milligram per 100 gram. The quality of *Castanea mollissima* cv. "Zunhua pagoda 54" turned out to be the top compared with chestnut across the country. In addition, 80% of Zunhua chestnuts were exported to Japan and many Southeast Asian countries, earning a great reputation in the international arena.

2.2. Experiment Materials

According to research objectives, new varieties *Castanea mollissima* cv. "Zipo", "Zunyu", which were bred during "The Eleventh Five-year Plan" in China and the traditional Yan Mountain cultivars *Castanea mollissima* cv. "Duanci", "Yanhong", "Donglingmingzhu" as research materials for mutual pollination on the basis of germplasm resources survey. Pollens of all 5 varieties were respectively collected for reciprocal pollination and varieties selection are as followed in **Table 1**.

There were totally 25 combinations and the design is as follows in **Table 2**.

2.3. Test Method

The research materials were healthy, non-pest, well-managed and in similar growth conditions. 20-year-old *Castanea mollissima* cv. "Yanhong", "Zunyu", "Zipo", "Dong-

Table 1. Varieties selection.

Number	Variety	Code
1	<i>Castanea mollissima</i> cv. "Yanhong"	A
2	<i>Castanea mollissima</i> cv. "Zunyu"	B
3	<i>Castanea mollissima</i> cv. "Zipo"	C
4	<i>Castanea mollissima</i> cv. "Donglingmingzhu"	D
5	<i>Castanea mollissima</i> cv. "Duanci"	E

Table 2. Pollination combinations design.

Male	Female				
	A	B	C	D	E
A	A × A	A × B	A × C	A × D	A × E
B	B × A	B × B	B × C	B × D	B × E
C	C × A	C × B	C × C	C × D	C × E
D	D × A	D × B	D × C	D × D	D × E
E	E × A	E × B	E × C	E × D	E × E

lingmingzhu" and "Duanci" were respectively and randomly selected as female parent. 7 - 8 similar female flowers in the east, west, north and south of each tree were picked out for pollination and there were totally 30 flowers in each tree.

The process of pollination is as follows:

Ziplock bags were applied to bag the female flowers before their stigmas" appearing.

It was the most appropriate season for pollination when the angle between stigma and stigma became 30° - 45° and most anther of male inflorescence turned yellow from green at this time. Ziplock were put on the female flowers again immediately after the pollination. The job was repeated two times 2 days later.

Bags were taken off from the female flower and tags were hanged to branches to indicate male parents when all male flowers withered. Meanwhile, fruiting rate were calculated.

Gather chestnut and investigate their empty shell rate, seed-setting rate and so on after the chestnut was harvested.

2.4. Statistics

The number of female inflorescence was recorded when pollinating. The fruiting condition was written down while ziplock bags were removed after all male flowers had withered and the number of empty shell, number of nut per burr, nut weight and yield were recorded when chestnut were collected.

The experimental data, in which self-pollination combinations were considered as the comparison, were analyzed by average method and variance analysis, applying mean square error test method by spss17.0 statistical software.

3. Result and Discussion

3.1. Affect from Different Combinations on Fruiting Rate and Seed-Setting Rate

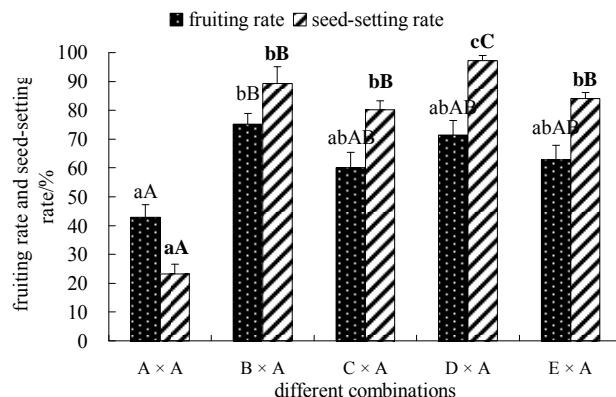
Empty shell of chestnut, commonly known as no fruit, means nuts in shells did not develop or just leave the seed coat [12-14]. It is considered as no empty shell even when there is only one seed in it. To some extent, the level of seed-setting rate can be used as indicator for strength of pollination affinity. That is, the higher the seed-setting rate is, the stronger the affinity will be and it could be considered as a good combination [15]. Meanwhile, seed-setting rate is considered to be a key factor to effect the yield [16]. So a cross-pollination experiment was carried out on *Castanea mollissima* cv. “Yanhong”, “Zunyu”, “Zipo”, “Donglingmingzhu” and “Duanci and fruiting rate and seed-setting rate of 5 cultivars are follows as Figures 1-5.

It can be seen from Figure 1 that: both fruiting rate (42.9%) and seed-setting rate (23.3%) of self-pollination combination “Yanhong × Yanhong” (A × A) was very low. However, fruiting rate and seed-setting rate of cross-pollination combinations “Zunyu × Yanhong” (B × A), “Zipo × Yanhong” (C × A), “Donglingmingzhu × Yanhong” (D × A) and “Duanci × Yanhong” (E × A) were significantly higher than that of “Yanhong × Yanhong” (A × A), which reached the same result with Fan Wenbang [17].

Considering different cross-pollination combinations, seed-setting rate showed significant difference, but the fruiting rate of the 4 cross-pollination combinations showed no evident difference with each other.

Figure 2 showed that fruiting rate and seed-setting rate of self-pollination combination “Zunyu × Zunyu” (B × B) was only 61.0% and 26.5%. Although seed-setting rate of cross-pollination combination “Yanhong × Zunyu” (A × B) (91.5%) was the highest of all, its fruiting rate decreased even lower as against that of the self-pollination combination “Zunyu × Zunyu” (B × B). Thus, “Yanhong” was considered not to be the suitable pollination tree for “Zunyu”. Difference among fruiting rate of “Zipo × Zunyu” (C × B) (81.0%), “Donglingmingzhu × Zunyu” (D × B) (79.1%) and “Duanci × Zunyu” (E × B) (78.1%) were not so evident, while seed-setting rate of “Zipo × Zunyu” (C × B) (93.8%) and “Duanci × Zunyu” (E × B) (73.9%) was lower than that of “Donglingmingzhu × Zunyu” (D × B) (95.0%). Meanwhile, fruiting rate showed no significant difference with each other among the 5 combinations, but on the contrary, seedsetting rate manifest much difference with each other, which indicates that fruiting rate and seed-setting rate were not so consistent with each other and the condition of fruiting rate did not affect seed-setting rate much.

As shown in Figure 3 that fruiting rate (73.3%) and seed-setting rate (44.5%) of self-pollination combination “Zipo × Zipo” (C × C) were still the lowest of all. All seed-setting rate of combinations “Yanhong × Zipo” (A × C), “Zunyu × Zipo” (B × C), “Donglingmingzhu × Zipo”



a: Small letters on the post indicate significance level on 5% and capital letters indicated significance level on 1%. Letters in bold described differences between seed-setting rate and those letters in light showed differences between fruiting rate and it applies to Figure 1-5 .

Figure 1. Fruiting and seed-setting conditions of Yanhong (A) under different pollinations.

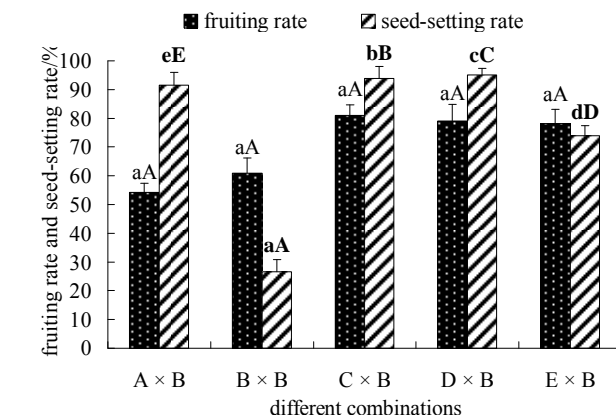


Figure 2. Fruiting and seed-setting conditions of Zunyu (B) under different pollinations.

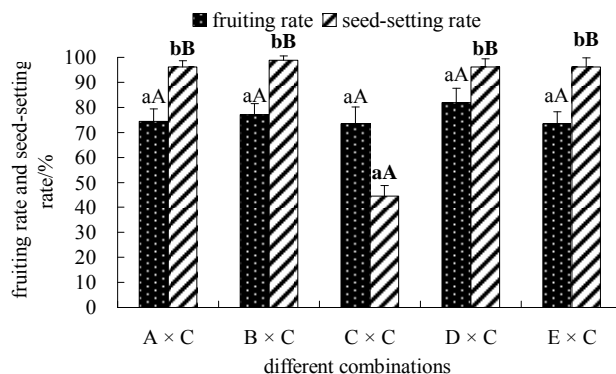


Figure 3. Fruiting and seed-setting conditions of Zipo (C) under different pollinations.

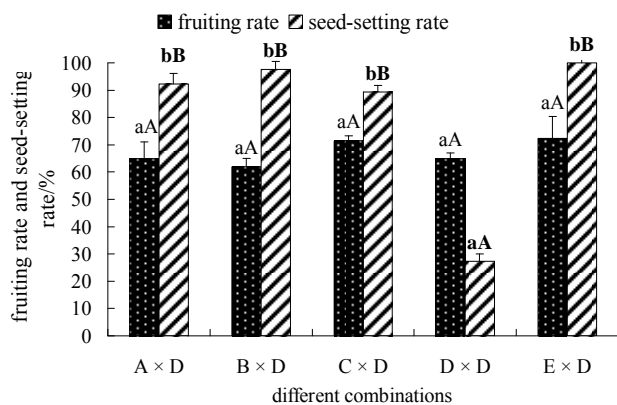


Figure 4. Fruiting and seed-setting conditions of *Donglingmingzhu* (D) under different pollinations.

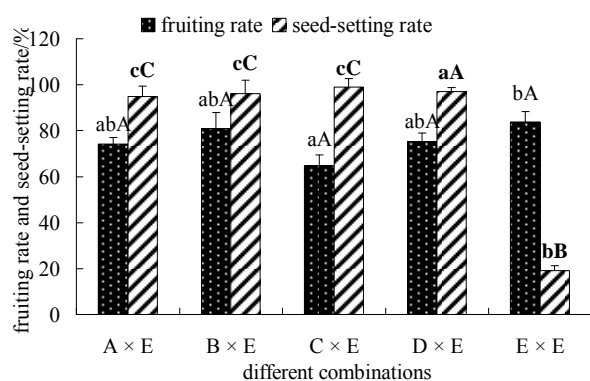


Figure 5. Fruiting and seed-setting conditions of *Duanci* (E) under different pollinations.

(D × C) and “*Duanci* × *Zipo*” (E × C) were above 95%. However, considering fruiting rate, “*Donglingmingzhu* × *Zipo*” (E × C) (81.9%) was higher than that of “*Yanhong* × *Zipo*” (A × C) (74.3%), “*Zunyu* × *Zipo*” (B × C) (77.1%), “*Duanci* × *Zipo*” (E × C) (73.3%). Fruiting rate did not show evident difference among these 5 varieties and seed-setting rate of the 4 cross-pollination combinations also showed no significant difference between each other.

Figure 4 showed that fruiting rate of self-pollination combination “*Donglingmingzhu* × *Donglingmingzhu*” (D × D) was 64.9%, but its seed-setting rate was only 27.3%. In comparison with “*Yanhong* × *Donglingmingzhu*” (A × D) (64.8%) and “*Zunyu* × *Donglingmingzhu*” (B × D) (61.9%), seed-setting rate of “*Zipo* × *Donglingmingzhu*” (C × D) (71.4%) and “*Duanci* × *Donglingmingzhu*” (E × D) (72.4%) were much more higher. However, fruiting rate of “*Zipo* × *Donglingmingzhu*” (C × D) (89.3%) was much lower than that of “*Duanci* × *Donglingmingzhu*” (E × D) (100%).

It can be seen from **Figure 5** that fruiting rate of self-pollination combination “*Duanci* × *Duanci*” (E × E) was 83.8%, but its seed-setting rate was only 19.0%. From the 4 figures above this we can see all of self-pollination combinations “*Yanhong* × *Yanhong*” (A × A), “*Zunyu* ×

“*Zunyu*” (B × B), “*Zipo* × *Zipo*” (C × C) and “*Donglingmingzhu* × *Donglingmingzhu*” (D × D) depicted the same thing that fruiting rate of them were the lowest of all. That is because the stigma of pistil has strong selectivity on pollen, which leads to infertility under self-pollination conditions [18]. Seed-setting rate of all the other 4 cross-pollination combinations were very high, especially “*Zunyu* × *Duanci*” (B × E) and “*Zipo* × *Duanci*” (C × E), both of which were over 95.0%. Seed-setting rate of the 4 cross-pollination combinations showed significant difference in comparison with that of self-pollination combination “*Duanci* × *Duanci*” (E × E), but in which “*Yanhong* × *Duanci*” (A × E), “*Zunyu* × *Duanci*” (B × E) and “*Zipo* × *Duanci*” (C × E) depicted no evident difference with each other.

In all, cross-pollination had a significant impact on fruiting rate and seed-setting rate of chestnut. Although there were some difference among cross-pollination combinations, they were not so significant.

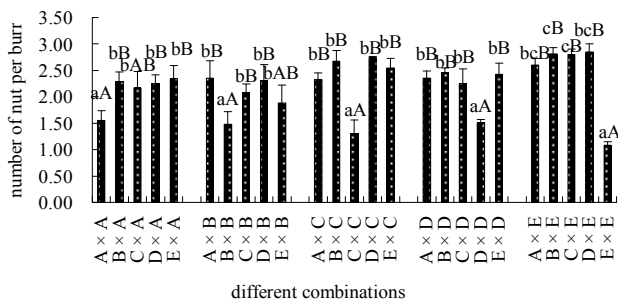
3.2. Affect from Different Combinations on Number of Nut per Burr

As can be indicated in **Figure 6**: number of nut per burr of *Castanea mollissima* cv. “*Yanhong*” (A), “*Zunyu*” (B), “*Zipo*” (C), “*Donglingmingzhu*” (D) and “*Duanci*” (E) were respectively 1.56, 1.48, 1.30, 1.50 and 1.08.

By comparison with self-pollination combination “*Yanhong* × *Yanhong*” (A × A), the average number of nut per burr of “*Zunyu* × *Yanhong*” (B × A), “*Zipo* × *Yanhong*” (C × A), “*Donglingmingzhu* × *Yanhong*” (D × A) and “*Duanci* × *Yanhong*” (E × A), increased from 1.56 to 2.26 after cross-pollination, 45% higher than that of “*Yanhong* × *Yanhong*” (A × A), in which combination “*Duanci* × *Yanhong*” (E × A), whose number of nut per burr became 2.34, turned out to be the highest and was 1.5 times as much as that of “*Yanhong* × *Yanhong*” (A × A).

The average number of nut per burr of “*Yanhong* × *Zunyu*” (A × B), “*Zipo* × *Zunyu*” (C × B), “*Donglingmingzhu* × *Zunyu*” (D × B) and “*Duanci* × *Zunyu*” (E × B) rose from 1.48 to 2.16 after cross-pollination, 46% higher than that of “*Zunyu* × *Zunyu*” (B × B), in which combination “*Yanhong* × *Zunyu*” (A × B), whose number of nut per burr was 2.35, ranked first among the cross-pollination combinations and turned out to be 59% higher than that of “*Zunyu* × *Zunyu*” (B × B).

The average number of nut per burr of “*Yanhong* × *Zipo*” (A × C), “*Zunyu* × *Zipo*” (B × C), “*Donglingmingzhu* × *Zipo*” (D × C), and “*Duanci* × *Zipo*” (E × C) has nearly doubled by comparison with that of self-pollination combination “*Zipo* × *Zipo*” (C × C), rising from 1.30 to 2.57 after cross-pollination and 98% higher than that of “*Zipo* × *Zipo*” (C × C), in which combination “*Zunyu* × *Zipo*” (B × C), whose number of nut per burr



b, Small letters on the post indicate significance level on 5%, capital letters indicate significance level on 1%. These letters just showed differences in the corresponding group (e.g. The first group were composed by A × A, B × A, C × A, D × A and E × A, so the letters on their post just indicated differences among A × A, B × A, C × A, D × A and E × A, not relating to the other 4 groups, neither did the letters on the post of the other 4 groups) and it also applies to **Figure 7**.

Figure 6. Number of nut per burr of different varieties.

become 2.73, ranked first among the cross-pollination combinations and was 133% higher than that of “Zipo” (C × C).

By comparison with self-pollination combinations “Donglingmingzhu × Donglingmingzhu” (D × D) and “Donglingmingzhu × Duanci” (E × E), the average number of nut per burr of “Donglingmingzhu” (D) and “Duanci” (E) respectively increased from 1.50 to 2.37 and 1.08 to 2.77 after cross-pollination, both increased rapidly by 58% and 156%. According to the figure, “Zunyu × Donglingmingzhu” (B × D) and “Duanci × Donglingmingzhu” (E × D), whose number of nut per burr were 2.45 and 2.85, turned out to be the highest in the corresponding combinations, respectively 1.63 and 2.64 times as much as that of “Donglingmingzhu × Donglingmingzhu” (D × D) and “Donglingmingzhu × Duanci” (E × E).

According to the figure given above, 5 sets of data depicts the same result that evident consistent positive effect was found in number of nut per burr in all of the 5 varieties after cross-pollination.

3.3. Affect from Different Combinations on Nut Weight

Nut weight of chestnut is a very important economic characteristic related to varieties evaluation [19,20]. **Figure 7** showed that nut weight of “Yanhong” (A), “Zunyu” (B), “Zipo” (C), “Donglingmingzhu” (D) and “Duanci” (E) under self-pollination were respectively 11.63 gram, 9.31 gram, 9.44 gram, 5.86 gram, 10.53 gram. Nut weight of “Zunyu × Yanhong” (B × A) (8.96 gram) was the heaviest among combinations crossed with “Yanhong” (A), nut weight of “Zipo × Zunyu” (C × B) (7.47 gram) ranked first by comparison with combinations crossed with “Zunyu” (B), “Zunyu × Zipo” (B × C) (7.64 gram) had the heaviest nut weight among combinations crossed with “Zipo” (C), nut weight of “Yanhong × Donglingmingzhu” (A × D) (5.25 gram) and

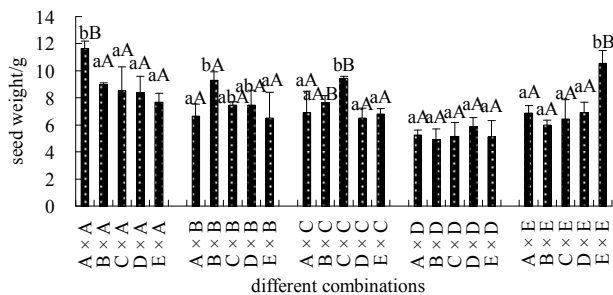


Figure 7. Nut weight of different varieties.

“Yanhong × Duanci” (A × E) (6.87 gram) respectively turned out to be first among combinations crossed with “Donglingmingzhu” (D) and “Duanci” (E). It indicated that nut weight of each self-pollination combination was the highest, and all of nut weights of these cross-pollination combinations were evidently lower than that of the corresponding self-pollination combinations except for “Donglingmingzhu” (D). However, difference among nut weight of cross-pollination combinations were not evident, which indicates that nut weight showed no significant difference in Xenia Effect and reached the same result with Zhou Jing [18].

3.4. Affect from Different Combinations on Yield

The variety which could improve seed-setting rate and fruiting rate of the female parent most was always considered to be the best to combine with it according to many references. However, yield of these female parents would probably not be the highest. It can be seen from **Figure 7** that difference about seed-setting rate, fruiting rate, number of nut per burr and nut weight were not so significant among different varieties. However, **Figure 8** showed that yield differences were significant among these varieties. Therefore, yield is decided by these 4 factors: seed-setting rate, fruiting rate, number of nut per burr and nut weight.

From **Figure 8** we can see that yield of “Yanhong” (A), “Zunyu” (B), “Zipo” (C), “Donglingmingzhu” (D) and “Duanci” (E) under self-pollination were significantly lower than that of under cross-pollination. “Zunyu” (B) improved the yield of “Yanhong” (A) most; “Donglingmingzhu” (D) was regarded as the best tree to improve “Zunyu” (B)’s yield; the best variety to improve “Zipo” (C)’s yield was “Zunyu” (B); “Donglingmingzhu” (D) and “Duanci” (E) improved each other most.

4. Conclusions

4.1. Assessment on Relationship between Cross-Pollination and Fruiting Conditions

One of the key points to improve yield and quality of chestnut is to make sure the pollination tree configured

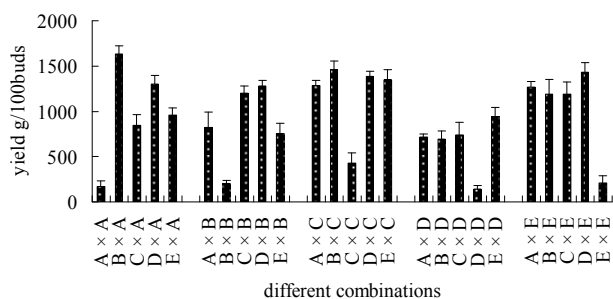


Figure 8. Yield of different varieties.

properly, because stigma of pistil has strong selectivity on different varieties pollen. Different pollination trees would lead difference in fruiting rate and seed-setting rate. The study on fruiting rate and seed-setting rate of 5 varieties of Yan Mountain chestnut indicated that: cross-pollination had a significant impact on both fruiting rate and seed-setting rate. Differences of seed-setting rate among cross-pollination were evident, but not so significant among fruiting rate.

4.2. Assessment on Affect from Different Combinations on Number of Nut per Burr

Artificial pollination test conducted on chestnut by Xia Renxue showed: by comparison with cross-pollinations trees, empty shell rate of self-pollination trees was 17.9% higher, and the average nut number per burr was 0.74 lower [21]. What's more, experiment about fruiting and seed-setting characteristics of 8 self-pollination chestnut cultivars carried out by Liu Qingxiang of Hebei province also showed that the average nut number per burr greatly decreased under self-pollination conditions [22]. Figure 6 showed that empty shell rate of 5 Yan Mountain chestnut varieties which was self-pollinated is extremely high. However, there came a rapid increase on average nut number per burr after cross-pollination, which proved that cross-pollination did significantly promote the nut number per burr of 5 Yan Mountain chestnut varieties. As a result, it depicts the same conclusion with Xia Renxue and Liu Qingxiang. At the same time, diversification of nut number per burr of 5 female parents was basically the same and they all changed according to nuts content of corresponding male parents.

4.3. Affect from Different Combinations on Nut Weight

The 5 varieties of chestnut demonstrated the same thing that nut weight of each self-pollination combination rank first in all. Nut weight of cross-pollination combinations decreased greatly as against that of self-pollinations combinations except for *Castanea mollissima* cv. "Donglingmingzhu" (D). However, nut weight of cross-pollinations showed no significant difference with each other,

which revealed that nut weight showed no significant difference in Xenia Affection and depicts the same conclusion with Zhou Jing [18].

4.4. Affect from Different Combinations on Yield

The variety which promoted yield of *Castanea mollissima* cv. "Yanhong" (A), "Zunyu" (B), "Zipo" (C), "Donglingmingzhu" (D) and "Duanci" (E) most was not necessarily the variety which improved its fruiting rate and seed-setting rate most, because yield was decided not only by fruiting rate, seed-setting rate, but also by nut number per burr and nut weight. Figure 8 indicated that yield of cross-pollination combinations differ much from each other, and the comprehensive effect of fruiting rate, seed-setting rate, nut number per burr and nut weight had extremely significant effect on the yield.

Yield of self-pollination combinations were extremely lower than that of cross-pollinations, in which *Castanea mollissima* cv. "Zunyu"(B) improved the yield of "Yanhong" (A) most; "Donglingmingzhu" (D) was regarded as the best tree to improve "Zunyu" (B)'s yield; the best variety to improve yield of "Zipo" (C) was "Zunyu"(B); "Donglingmingzhu" (D) and "Duanci" (E) improved each other most.

5. Acknowledgements

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