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Early growth analysis and evaluation of 21 *Eucalyptus* clones in Leizhou Peninsula

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Abstract The growth, morphology, and wind resistance of 21 *Eucalyptus* clones were investigated and analyzed in Leizhou Peninsula, Zhanjiang city. The results showed that coefficient of variation of each index phenotype varied from 15.21%—42.46%. There were significant differences among the clones in growth indexes. The top five clones with high individual volume were JJ144, 2#, 28#, 9#, and JJ197. The morphological indexes were significantly different among the clones. There were also significant differences among the clones in wind resistance index, and the clones with good wind resistance were 28#, JJ162, JJ195 and JJ215, their preservation rate were more than 80%. It was found that tree height and DBH significantly correlated to individual volume, and stem form was significantly related to branch. Using the principal component analysis, it was determined that JJ144, 2#, 28#, 9# and JJ162 were the excellent clones with good performance in the Leizhou area.

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Introduction

Eucalyptus is the name of the species of Myrtaceae, *Angophora* Cav., *Corymbia* K.D.Hill & L.A.S.Johnson and *Eucalyptus* L., Herit (Wang, 2010). Most of them naturally grow in Australia, and a few of them are distributed in Indonesia, Papua New Guinea, Philippines, and some other places (Qi, 2002). Our country began to introduce *Eucalyptus* from 1890, and the history was more than 120 years. *Eucalyptus* has become the most important industrial timber species in southern China due to its fast growth, high yield, good material for utilization, and good economic returns (Xie, 2003). Clonal afforestation is favourable due to orderly forest form, high yield, and intensive management. It has been the main approach to *Eucalyptus* afforestation in southern China (Lu, 2005). The early selection of clones is a comprehensive selection of suitable local clones in accordance with the breeding objectives (Zhou, 2006). However, large-scale planting of a single genotype and clones of the sub-succession will lead to slow growth, decreased production, increased pests and diseases and environmental degradation (Lu, 2005). A continuous work of selection of fine clones and update varieties

should be carried out.

Because of high frequency typhoon, Leizhou Peninsula has a huge economic loss every year. Between July and September 2014, the typhoon "Amazon" and "Seagull" caused about 27,000 hm^2 of forest suffered from serious damage in State-owned Leizhou forestry bureau. More than 11,000 hm^2 of the forest were wind down, or wind-breakage, and they need to be cut down for reforestation (Zhu et al. 2016). Thus, it is particularly important to choose wind resistance varieties suitable for growing in the Leizhou area.

At present, there are many studies on *Eucalyptus* clones. Guo et al. (2012) investigated the growth traits of 25 clones of five tree species including *Eucalyptus grandis*×*E. camaldulens*, *E. grandis*×*E. urophylla*, *E. urophylla*×*E. grandis*, *E. camaldulensis* and *E. grandis* in Yibin city, Sichuan province. The result showed that there were significant differences in tree height, DBH and volume between different clones. Xiao et al. (2014) evaluated 11 *Eucalyptus* clones at age of 6 in Jiangmen city, Guangdong province in terms of the tree height, DBH and volume, windfall rate and preservation rate and found that clone 196 was the most suitable for cloning in this area. Cui et al. (2017) made an adaptability evaluation on 10 *Eucalyptus* clones in six different site conditions in Guangdong and Guangxi provinces based on of survival rate, tree height, DBH, incidence, wind damage rate and volume traits. The result showed that the wind-resistant clone LH9224 could be best planted in the typhoon zone; Clones DH3213 and DH3327 in inland areas of rare wind damage; In Tang area and some other areas, clone M1 should be chosen for the highest survival rate and clone LH9211 for better disease-resistance; For the areas of Wuchuan and Suixi with poor forest yield, the best choice is to plant fast-growing clone DH3213. Li et al. (2012) analyzed the growth and morphological traits of 36 *Eucalyptus* clones of 5.5 years old in southern Fujian. The results showed that the most suitable clones were the *Eucalyptus* hybrid clones with the genetic background of *E. urophylla*, *E. grandis* or *E. camaldulensis*. The above reports indicate that the growth performance of *Eucalyptus* clones varies in different places. Before the large-scale afforestation, growth comparison for cultivated strains in target area is required for a comprehensive and proper selection of varieties from various tree species, hybrid parents and clones. Therefore, this study carried out comparative experiments on the growth of 21 *Eucalyptus* clones in the Leizhou Peninsula area. The early comprehensive evaluation could provide the research basis for the breeding of excellent clones with high yield and strong wind resistance in Leizhou Peninsula.

Materials and methods

Study area

The test field is in Jijia forest farm of Leizhou Forestry Bureau (109°51′E, 20°53′N). This region a maritime monsoon climate. The average annual temperature of this area is 23.5 °C, and the annual rainfall is above 1,567 mm. May to September is a tropical storm season in this area. The strongest wind can be observed in August to September, accompanying with heavy rainfall accounting for 85.5% of the year. The forest land is flat, and the deep and fertile soil is dominated by laterites derived from basalt.

Experimental materials and field operation

Totally, 21 *Eucalyptus* clones were tested in this study (Table 1). They were selected from experimental *E. urophylla* forest by Leizhou research institute of forestry in 2013. The saplings were obtained by tissue culture. Afforestation time was at June 8, 2014. Planting spacing of 1.33 m×3 m, the planting density was 2,505 plants/hm^2.

Experimental design

The experiment was random block design, 3 lines and 12 units in one plot. The 10 surviving plants growing in the middle of each plot were selected to investigate the tree height, DBH, branch height, crown width, stem form and branch (If the number of surviving plants in the middle of the plot was less than 10, 10 plants were randomly selected at the other spots in the plot; if the number of surviving plants less than 10 plants, all strains survived were investigated). On September 7, 2016 growth parameters (tree height, DBH, individual

Table 1 Information of tested clones

Clone number	Tree species	Clone number	Tree species
JJ214	LH1×*E. 12ABL*	JJ215	LH1×*E. camaldulensis*
JJ162	*E. wetarensis*×*E. grandis*	JJ168	*E. tereticornis*×*E. pellita*
JJ195	*E. urophylla*	JJ171	*E. tereticornis*×*E. grandis*
JJ189	*E. urophylla*	16#	*E. urophylla*×*E. tereticornis*
JJ190	*E. urophylla*	9#	*E. urophylla*×*E. tereticornis*
JJ144	*E. urophylla*	10#	*E. urophylla*×*E. tereticornis*
JJ200	*E. urophylla*	14#	*E. urophylla*×*E. tereticornis*
JJ209	*E. urophylla*	27#	*E. urophylla*×*E. tereticornis*
JJ204	*E. urophylla*	2#	*E. urophylla*×*E. tereticornis*
JJ197	*E. urophylla*	28#	*E. urophylla*×*E. tereticornis*
JJ194	*E. urophylla*		

volume, branch height, crown width, height-diameter ratio), morphological indicators (stem form, branch), wind resistance indicators (the preservation rate after typhoon) were investigated for all plots.

(1) The individual volume is calculated as follows (Mo, 2005):

$$V = 0.0000628767 H^{0.96436} D^{1.821621}$$

Where V is the individual volume (m³); D is the DBH (cm); H is the tree height (m).

(2) Stem form, branch index was surveyed using visual method for scoring standard as described in Lu et al. (2010):

Stem form index was scored at 4 levels: Level I: straight and round trunk, scoring 4 points; Level II: straight trunk, not round, 3 points; Level Ⅲ: trunk slightly curved, not round, 2 points; and Level IV: trunk has two bending, 1 point.

Branch is classified into three grades: grade I: small lateral branches, symmetrical crown, scoring 3 points; grade II: moderate lateral branches, symmetrical crown, 2 points; and grade Ⅲ: big branch, not symmetrical crown, 1 point.

(3) Investigation of the post-typhoon survival rate: all the trees of each clone was tallied to determine: post-typhoon survival rate = number of preserved plants / total number of plants × 100%.

Data analysis

The data of 27 months were analyzed, and the growth indexes and morphological indexes were calculated by mean value. The stem form and branch score were analyzed by square root and then statistically analyzed (Lu, 2005). The text of the stem form, branch was converted data.

Data were sorted with Microsoft Excel 2003. SAS 9.3 (Huang & Xie, 2001) were used to analyze the indexes. Growth, morphological indicators were analyzed using two factors analysis of variance. The preservation rate was analyzed by two-way GLM, using Duncan's for multiple comparisons. Pearson correlation analysis was used to analyze the correlation between the indexes. The principal component analysis was used to evaluate the quality of the clones.

Results

Variance of different clones

The differences in tree height, DBH, individual volume, branch height, crown width, stem form, branch, height-diameter ratio, and preservation rate of 21 *Eucalyptus* clones were analyzed (Table 2). There were some differences between the indicators of *Eucalyptus* in the clones. The tree height varied with clones from 5.10 m to 13.80 m. The maximum difference of the DBH was 9.25 cm. The variation range of individual volume was 0.008,3 m³ to 0.061,5 m³. The minimum and maximum values of the branch height were 0.11 m and 9.00 m,

respectively. The range of crown width was 2.07 m. The variation range of stem form and branch in the clones were 1.00 to 2.00 points, 1.00 to 1.73 points, respectively. The minimum and maximum height-diameter ratio were 0.57, 2.38. The variation range of the preservation rate was 29.63% –89.82%. The variation coefficients of individual volume, branch height and preservation rate were high, which indicated that the differences between the three indexes was obvious.

Variance analysis of the indicators of clones

The variance analysis of the growth indexes, morphological indexes and wind resistance index of the clones at 27 months (Table 3) showed that the differences in the growth, morphology and wind resistance among tested clones were significant. For example, there were significant differences in tree height, DBH, individual volume, branch height, crown width, height-diameter ratio, stem form, and branch and preservation rate among the tested clones. Selecting fast growth, high yield, straight stem form, symmetrical crow, strong wind resistance of the 21 clones is feasible. In addition to tree height, crown width and stem form, the remaining indicators in the difference between the blocks was significant, indicating that the environment difference between the blocks had a certain impact on the clones.

Multiple comparative analysis of the indicators of clones

The multiple comparisons of each index (Table 4) showed that there were significant differences in the indicators among the tested clones, especially the difference between tree height and branch height. There were 11 clones with individual volume greater than the average, and the individual volume of clones JJ144 was the greatest. Their average height, average DBH, average individual volume, average branch height, the average stem form, average crown width, average branch, the average height-diameter ratio and the average preservation rate were 11.12 m、9.52 cm、0.039,9 m^3、6.23 m、1.18 m、1.52 point、1.42 point、1.18、70.33%, respectively. The clones 2# and JJ144 won the better stem form with values of 1.57 points and 1.52 points, respectively. The clones JJ144, and 2# were the best in branch with values of 1.42 points and 1.39 points, respectively. Clone 28# was determined as the strongest wind resistance clone as proved by the highest preservation rate.

Correlation analysis between indicators

The correlation analysis among the indexes (Table 5) showed that the correlation between tree height, DBH and individual volume was a significant positive correlation (correlation coefficient of 0.824,1—0.976,3). And the correlation coefficient between DBH and individual volume was the highest. There was a significant positive correlation between stem form and branch, the correlation coefficient was 0.718,1, and the height-diameter ratio was negatively correlated with other indexes. The

Table 2 Statistics of the indicators of tested *Eucalyptus* clones

Traits	Average value	Standard deviation	Minimum value	Maximum value	Coefficient of variation/%
H/m	9.78	1.49	5.10	13.80	15.21
D/cm	8.26	1.85	3.25	12.50	22.37
V/m^3	0.0295	0.0124	0.0083	0.0615	42.18
BH/m	5.06	2.15	0.11	9.00	42.46
Cr/m	1.38	0.29	0.66	2.73	20.79
SF/point	1.37	0.25	1.00	2.00	18.56
Br/point	1.30	0.21	1.00	1.73	16.30
H/D	1.21	0.21	0.57	2.38	17.54
SUR/%	62.95	18.09	29.63	89.82	28.73

Note: The stem form, the branch value is the square root processed value. In the table, H is tree height, D is DBH, V is individual volume, BH is branch height, Cr is crown width, SF is stem form, Br is branch, H/D is height-diameter ratio, SUR is preservation rate (hereafter).

Table 3 Two-factor analysis of variance of each indicator

Traits	Block			Clone			Block*Clone		
	Degrees of freedom	F value	*P* value	Degrees of freedom	F value	*P* value	Degrees of freedom	F value	*P* value
H	2	2.82	0.0602	20	11.81**	<.0001	39	3.8**	<.0001
D	2	15.66**	<.0001	20	8.27**	<.0001	39	1.22	0.1785
V	2	8.8**	0.0002	20	10.38**	<.0001	39	1.49*	0.031
BH	2	62.68**	<.0001	20	13.54**	<.0001	39	3.03**	<.0001
Cr	2	2.87	0.0574	20	16.8**	<.0001	39	1.49*	0.0312
H/D	2	8.99**	0.0001	20	4.96**	<.0001	39	1.44*	0.0449
SF	2	0.76	0.47	20	7.51**	<.0001	39	2.8**	<.0001
Br	2	10.47**	<.0001	20	2.57**	0.0002	39	1.44*	0.044
SUR	2	3.81*	0.0307	20	2.82**	0.0026	-	-	-

Note: When the probability of 0.01 <*P* value <0.05, the difference is significant, expressed as *. *P* value <0.01, the difference is extremely significant, expressed in ** (hereafter).

Table 4 Multiple comparative analysis of nine indicators

Clone	H/m	D/cm	V/m^3	BH/m	Cr/m	H/D	SF/point	Br/point	SUR/%
2#	11.13a	9.59a	0.0395a	6.00abcd	1.65ab	1.17bcde	1.57a	1.39ab	66.67abcd
JJ144	11.12a	9.52ab	0.0399a	6.23abc	1.18h	1.18bcde	1.52ab	1.42a	70.33abcd
9#	10.69ab	8.94abc	0.0365ab	5.44cdef	1.48cdef	1.18bcde	1.49ab	1.37abc	66.67abcd
28#	10.51abc	9.46ab	0.0390a	6.49ab	1.40efg	1.14cde	1.32defg	1.36abc	90.00a
JJ162	10.41bcd	8.16cdefg	0.0301cde	6.75a	1.31g	1.29b	1.26fgh	1.28bcdef	88.00a
JJ197	10.33bcde	8.94abc	0.0356abc	4.67fgh	1.52bcde	1.20bcde	1.51ab	1.29bcdef	29.67e
10#	10.05bcdef	8.48cde	0.0299cde	3.82hi	1.55bcd	1.21bcde	1.41bcde	1.32abcde	65.67abcd
27#	9.97cdef	8.21cdef	0.0298cde	5.04defg	1.69a	1.26bcd	1.41bcde	1.29bcdef	75.00abc
JJ189	9.80cdefg	8.25cdef	0.0282def	5.77bcde	1.18h	1.21bcde	1.45abcd	1.35abc	55.33abcde
JJ214	9.78defg	8.83abcd	0.0319bcd	5.25cdefg	1.48cdef	1.13de	1.43bcd	1.33abcde	68.33abcd
JJ195	9.75defg	8.07cdefg	0.0279def	6.21abc	1.14h	1.24bcde	1.22fgh	1.19f	83.33ab
16#	9.69defg	8.33cdef	0.0300cde	2.85j	1.51cde	1.20bcde	1.19gh	1.25cdef	47.33bcde
JJ190	9.60efgh	8.59bcde	0.0295cde	4.98efg	1.38efg	1.12e	1.40bcde	1.31abcdef	61.00abcde
14#	9.52fghi	8.21cdef	0.0280def	5.44cdef	1.17h	1.18bcde	1.35cdef	1.25cdef	47.33bcde
JJ204	9.21ghij	7.36fg	0.0222fg	4.80efg	1.17h	1.26bc	1.15h	1.21def	61.00abcde
JJ194	9.11ghij	7.89defg	0.0291cde	4.59fgh	1.41efg	1.21bcde	1.28efg	1.33abcd	37.00de
JJ171	8.96hij	7.72efg	0.0246efg	3.24ij	1.41efg	1.21bcde	1.46abc	1.32abcde	79.67ab
JJ209	8.94hij	6.00h	0.0149h	5.30cdefg	1.08h	1.5a	1.34cdef	1.25cdef	75.57abc
JJ215	8.81ij	7.19g	0.0209g	5.55bcdef	1.36fg	1.25bcd	1.34cdef	1.28bcdef	80.33ab
JJ200	8.68j	7.46fg	0.0259defg	2.56j	1.58abc	1.17bcde	1.33def	1.20ef	36.33de
JJ168	8.61j	7.83defg	0.0223fg	4.34gh	1.42defg	1.14cde	1.34cdef	1.30bcdef	40.00cde

Note: The same letter indicate that there is no significant difference at the 0.05 level (Duncan's method).

Table 5 Correlation analysis of each indicator

Correlation coefficient	H	D	V	BH	Cr	SF	Br	H/D	SUR
H									
D	0.8241**								
V	0.9121**	0.9763**							
BH	0.5717**	0.3190	0.3932						
Cr	0.1053	0.3531	0.3119	–0.4757*					
SF	0.5035*	0.4806*	0.5248*	0.1876	0.2459				
Br	0.6097**	0.5506**	0.5906**	0.4164	–0.0102	0.7181**			
H/D	–0.1763	–0.6859**	–0.5309*	0.1922	–0.4787**	–0.2013	–0.1580		
SUR	0.3219	0.0216	0.0945	0.5887**	–0.2994	0.0381	0.2668	0.3543	

Note: *, ** respectively represent significant and extremely significant levels.

preservation rate was positive correlated with the height of the branch (0.588,7) but was negative correlated with the crown width (–0.299,7). The main factor affecting the preservation rate was branch height. The higher the branch height, the stronger the wind resistance. And the larger the crown width, the weaker the wind resistance.

***Eucalyptus* clone principal component analysis**

Principal component analysis is a multivariate statistical method that transforms multiple indicators into a few independent indicators (Huang & Xie, 2001). The cumulative contribution rate of the first three principal components in the principal component analysis results (Table 6) was 82.25%, which reached the requirement of analysis (Zhang et al, 2016). The first principal component mainly covered the information of tree height, DBH and individual volume variables. The second principal component mainly covered the information of branch height, crown width, height-diameter ratio, and preservation rate variables. The third principal component mainly covered the information of stem form and branch. According to the three principal components and the corresponding components, constitute the three-principal component linear combination equations:

F_1=0.197X_1+0.218X_2+0.216X_3+0.086X_4+0.092X_5+0.157X_6+0.187X_7−0.135X_8+0.024X_9

F_2=0.152X_1−0.035X_2−0.015X_3+0.388X_4−0.308X_5−0.04X_6+0.042X_7+0.253X_8+0.362X_9

F_3=–0.097X_1−0.295X_2−0.251X_3−0.171X_4+0.242X_5+0.715X_6+0.404X_7+0.45X_8+0.11X_9

Where X_1–X_9 stands for tree height, DBH, individual volume, branch height, crown width, stem form, branch, height-diameter ratio, and preservation rate. The final score model was:

F=0.593F_1+0.288F_2+0.119F_3

The scores of the individual component of each clone are shown in Table 7.

Clones 2#, JJ144, 28#, 9#, and JJ197 obtained higher scores in the first principal component score. The growth of these five clones was generally good, and the volume of individual was high. Clones JJ209, JJ162, JJ195, JJ144, and 28# gained higher scores clones in the second principal component, indicating that these clones had small crown width, high branch height and high preservation rate. Clones JJ209, JJ171, 27#, 2#, and JJ215 had higher scores in the third principal component, suggesting that their stems were relatively straight, and the crown were symmetrical. Overall, JJ144, 2#, 28#, 9#, JJ162 had top higher composite scores than the rest. Therefore, these clones are recommended as the selected clones with the rapid growth, straight stem, strong wind resistance in the study area.

Conclusion and discussion

There was a significant difference in the growth status among the clones, and it was feasible to choose between clones. *Eucalyptus* is a tree species of short rotation

Table 6 Principal component analysis results

Item	F_1	F_2	F_3
Characteristic root	4.390	2.132	0.880
Variance contribution rate/%	48.783	23.694	9.778
Cumulative contribution rate/%	48.783	72.477	82.254
H	0.864	0.325	-0.085
D	0.957	-0.074	-0.260
V	0.949	-0.032	-0.221
BH	0.378	0.828	-0.151
Cr	0.406	-0.657	0.213
SF	0.691	-0.085	0.630
Br	0.823	0.089	0.355
H/D	-0.594	0.540	0.396
SUR	0.104	0.772	0.097

Table 7 Clonal components and comprehensive score

Clone	The first principal component score	The second principal component score	The third principal component score	Composite score	Ranking
JJ144	1.682	1.032	0.132	1.311	1
2#	1.877	0.009	0.843	1.216	2
28#	1.209	0.937	–1.284	0.834	3
9#	1.205	0.090	0.516	0.802	4
JJ162	–0.069	1.640	–0.695	0.349	5
JJ214	0.637	–0.260	–0.044	0.297	6
JJ189	0.177	0.471	0.414	0.290	7
27#	0.196	–0.119	0.878	0.186	8
JJ197	0.738	–1.042	0.254	0.168	9
10#	0.281	–0.583	0.680	0.080	10
JJ190	0.276	–0.380	–0.351	0.013	11
JJ171	–0.374	–0.468	1.607	–0.165	12
JJ195	–0.682	1.323	–1.786	–0.236	13
JJ215	–0.920	0.570	0.692	–0.299	14
14#	–0.341	0.033	–1.013	–0.313	15
JJ194	–0.325	–0.841	–0.230	–0.462	16
JJ209	–2.074	1.737	2.145	–0.474	17
JJ168	–0.627	–1.162	–0.049	–0.712	18
16#	–0.467	–1.299	–1.233	–0.797	19
JJ204	–1.407	0.380	–1.346	–0.885	20
JJ200	–0.993	–2.070	–0.129	–1.201	21

pulp. The volume determines the final yield of the pulp (Li, 2009). The top five of 21 *Eucalyptus* clones were JJ144, 2#, 28#, 9# and JJ197, respectively, because of the better growth and good quality. Guo et al (2012) analyzed the growth indicators of 2-year-old *Eucalyptus*, and also found that these parameters had extremely significant.

There was significant difference among the preservation rates of tested clones, indicating that it is feasible to select out of strong resistance to clones among tested 21 clones. This result is consistent with Wang et al. (2015) on wind resistance survey in Guangxi Dongmen forest farm of 20 *Eucalyptus* clones. Leizhou Peninsula is a typhoon-prone area and typhoon has a great impact on tree growth, so we need to choose strong wind resistance to promote the cultivation of clones. The clone 28#, JJ162, JJ195, and JJ215 had post typhoon preservation rate greater than 80%, indicating that they can be used as a wind resistance species for further observation and afforestation in the study area.

The correlation analysis among the indexes showed that the correlation between tree height, DBH and individual volume was significantly correlated with a correlation coefficient of 0.824,1–0.976,3, inparticular between DBH and individual volume. Lu (2005) and Luo (2012) also found the similar conclusion. However, there was no significant positive correlation between the stem form and the branch in the Luo's study, and the correlation coefficient was small, which was not consistent with the results of this study. This might be the stem form and the branch are artificially scored which was vulnerable to subjective influence.

Using the principal component analysis to evaluate the clones, and finally identified five fast-growing excellent *Eucalyptus* clones, namely JJ144, 2#, 28#, 9#, and JJ162. Clones JJ144, 28# and JJ162 were clones that had fast growing, strong wind resistance, and poor morphology. Clone 2# was fast-growing, stem straight, poor wind resistance. Clones 9# was the clone that had fast growing, moderate morphology and moderate wind resistance.

Although study area is located in Leizhou Peninsula with frequent typhoons and thunderstorms, in this study, we did not investigate the relevant investigation after the typhoon in time, and the use of the preservation rate after typhoon to represent the wind resistance may not reflect accurately the wind situation of the clones. In the future wind survey, the degree of wind damage to the forest is recorded by 5-level record system which is considered to be a more accurate wind resistance determination as described in Zhu (2016), should be used to a forest. The vertical angle between the trunk with 2 meters from the ground and horizontal plane can be used as a parameter to grading, and get the appropriate score (Zhu et al, 2016). The angle between 0 – 30 ° is scored 5, getting 5 points; the angle between 30 – 60 ° for 4, 4 points; the angle between 60 – 90 ° for 3, 3 points. The angle is 90 ° for 2, 2 points; and broken trees as 5, 1 point. The wind damage rate = number of damaged plants / total number of plants × 100%.

Early selection of clones can increase the impact of different locations in order to select the clones that are suitable for local growth. In the future, more traits (disease resistance and insect resistance) can be investigated, so that we can obtain better clones in all aspects. Early selection of the fine clones also needs to conduct regional trials and pilot, thus the optimization is accomplished, and eventually promoted to the local (Lu, 2005).

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