Comparing agronomic performance of breeding populations derived from anther culture and single-seed descent in rice

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This experiment was conducted to compare the breeding efficiency of anther culture (AC) and single-seed descent (SSD) methods. A total of 380 AC lines and 916 F_6 SSD lines derived from Ilpumbyeo/Nonganbyeo were evaluated for field performance of yield-related traits, including grain quality. No significant difference was found in mean comparisons of yield components between the two methods. There was a wide range of trait variation, and high transgressive segregation for each trait was detected among the populations derived from either the AC or SSD method. Regardless of breeding method, a high frequency of the desirable transgressive lines was found for the three traits (panicle length, number of grains per panicle, and fertility), indicating that selecting superior recombinants of these traits could be possible by either the AC or SSD method. The mean performance of agronomic traits in 45 selected elite lines and the five top-ranking lines did not differ significantly between the two breeding methods. Overall, the AC method produced a considerable extent of genetic variation and superior rice genotypes in the cross we used, implying that the AC method can be reliably used for the rice breeding program.

Anther culture and single-seed descent are two important breeding methods to speed up the breeding cycle. In the Korean program, anther culture plays an important role in rice breeding. It is possible to reliably obtain large numbers of inbred lines for selection from anther culture of japonica crosses, although there are still some problems in indica genotypes. A total of 15 varieties have been developed by anther culture breeding since the first anther-derived variety, Hwaseongbyeo, was released in 1985. These varieties currently account for around 25% of the rice-growing area in Korea. Despite the practical use of the technique in rice breeding, there is still a limited understanding of the potential for cultivar development via anther culture because of its inherent factors, such as genotypic dependence of androgenesis, the deleterious effect of somaclonal variation (Oono 1983), distortion in segregation by gametic selection during androgenesis (Murigneux et al 1993), and only one chance of recombination before fixation in the F_1 system (Snape 1976). These factors can influence genetic variation and the creation of desirable recombinants in the breeding lines derived from anther culture. In this study, we aimed to compare the breeding lines derived from anther culture and the single-seed descent method for field performance and to determine the extent of genetic variation and transgressive phenomenon for yield-related traits and quality characteristics.

Materials and methods

F_1 plants of Ilpumbyeo/Nonganbyeo and the parental genotypes were used to develop anther culture (AC) and single-seed descent (SSD) lines. The parents differ in agronomic plant characteristics. Anther culture was used with F_1 plants two times from 1993 to 1995. Vacuum-anther-plating was used according to the method of Moon et al (1994). Haploids and sterile plants were discarded and seed harvesting was done on fertile diploid plants. The R_1 generation was grown for seed multiplication in the rice field and a total of 381 lines of the R_2 generation were reserved for the population to be tested.

In the SSD method, 1,500 F_2 plants from 10 bulked F_1 seeds of the same cross above were grown in the field in 1994. Six hundred plants were randomly selected and a single seed was taken from each plant and advanced to the F_3 generation. SSD was done to reach the F_5 generation. All seeds were harvested from each F_5 plant (F_6 seed) and 916 lines of the F_6 generation were produced.

In 1996, the agronomic performance of AC and SSD lines for yield-related traits in AC and SSD populations was evaluated in the field. The physio-chemical traits of rice quality, including grain morphology, white core, white center, alkali digestion value, and amylose content, were assessed in the laboratory. We selected 45 superior lines with good agronomic traits by visual selection in the field from each AC and SSD population. In 1997, yield trials of selected lines were conducted in a randomized complete block design with three replications. The middle 10 plants were used for data collection. Heading date, culm length, panicle length, number of panicles, number of spikelets per panicle, fertility, and yield per plant were investigated and statistically analyzed.

Results and discussion

Agronomic traits and transgressive segregation of AC and SSD populations

The mean and range for yield and yield components of AC and SSD populations are shown in Table 1. The AC and SSD populations did not differ significantly in mean comparison for each trait except for number of spikelets per panicle. However, the AC population in actual value showed a slightly higher mean yield and a tendency of increased growth duration, tall height, and good fertility. The mean values of those traits in

Table 1. Mean and range for yield and yield components for lines derived from anther culture (AC) and single-seed descent (SSD).

Trait	AC		SSD			Mean of parents		
	M ± SE	Range	M ± SE	Range	D√[a]	Ilpumbyeo	MP	Nonganbyeo
Days to heading	117 ± 8.6	96–138	114 ± 9.4	94–141	3 ns	123	118	113
Culm length (cm)	78 ± 7.9	21–91	75 ± 7.9	25–114	3 ns	80	79	78
Panicle length (cm)	23 ± 2.3	12–31	23 ± 2.3	11–36	0 ns	22	23	23
Panicles plant^{-1} (no.)	14 ± 2.5	8–24	13 ± 2.8	6–32	1 ns	18	17	15
Spikelets panicle^{-1} (no.)	55 ± 38.7	36–260	161 ± 41.1	27–282	6*	156	151	146
Fertility (%)	88.7 ± 9.7	27–99	84.3 ± 20.5	10–99	4.4 ns	89	88	86
1,000-grain weight (g)	22 ± 2.8	12.5–25.9	21 ± 2.5	9.8–27.0	1 ns	22	21	20
Yield plant^{-1} (g)	32 ± 8.5	6–55	29 ± 10.4	2–55	3 ns	39	36	33

[a]D√ = difference of mean between AC and SSD. ns and * indicate not significant and significant at the 5% level.

Table 2. Percentage of transgressive lines for yield and yield components in anther culture (AC) and single-seed descent (SSD) lines.[a]

Breeding method	Days to heading		Culm length		Panicle length		Panicles plant^{-1}		Grains panicle^{-1}		Fertility		1,000-grain weight		Yield plant^{-1}	
	EH	LH	SC	TC	SP	LP	LPN	HPN	LGN	GN	LF	HF	LG	GW	LYD	YD
AC	23	6	22	5	4	18	32	1	22	34	13	2	7	31	36	5
SSD	60	12	60	17	4	50	43	2	12	43	41	16	14	26	55	7
χ^2	0.3 ns		0.2 ns		1.9 ns		0.1 ns		4.0 ns		1.4 ns		2.7 ns		0.2 ns	

[a]EH = early heading, LH = late heading, SC = short culm, TC = tall culm, SP = short panicle, LP = long panicle, LPN = low panicle number, HPN = high panicle number, LGN = low grain number, HGN = high grain number, LF = low fertility, HF = high fertility, LGW = low 1,000-grain weight, HGW = high 1,000-grain weight, LYD = low yield, HYD = high yield.

the AC population are closer to the mid-parental value. The standard deviations and ranges indicate that AC lines are distributed closer to the mean. In the SSD population, the mean agronomic value was lower than the mid-parental value, with a wider ranger of variation in the population, indicating a greater proportion of lines with negative extremes than in the AC population. Table 2 shows the appearances of transgressive lines for each trait within each AC and SSD population. There was a clear trend of transgression according to the traits regardless of breeding method. The absolute number of transgressive lines was higher in the SSD population.

Also, a significant difference was not noted between the two methods in grain morphology, including grain length, width, thickness, and physio-chemical traits such as white core and center, alkali digestion value, and amylose content (data not shown).

From the viewpoint of practical breeding, the appearance of superior recombinants in a population is the most important criterion for determining that a certain breeding or selection method could be effectively used in the breeding program. The above results suggest that either the AC or SSD method seems equally effective in obtaining desirable transgressive genotypes, although genetic variation and the absolute number of transgressive lines in the AC population were smaller than in the SSD population. The primary factor for successful anther culture breeding depends on the establishment of an appropriate breeding population. Wenzel et al (1995) reported that 100 AC lines from a cross are sufficient to obtain superior lines. Alternatively, the probability of obtaining the best recombinant can be enhanced by producing doubled-haploid (DH) lines from plants in later generations. An F_2-derived DH population may contain up to 50% more of the best recombinants than the F_1 system.

Yield test of selected AC and SSD lines

Forty-five elite lines were selected visually from each AC and SSD population in the field. Selections were made on lines with desirable traits such as good plant type, moderate plant height, long and good panicle shape, and high fertility. Table 3 shows the mean yield and yield components of 45 selected lines and the top five high-yielding lines from each breeding method. No significant difference in mean agronomic performance was detected between AC and SSD within each selected group, while the mean of the top five high-yielding lines consistently exceeded that of the 45 selected lines. When comparing the mean yield of the basic population from which selection was made in the previous year (Table 1), the 45 selected lines showed an increased yield of 12% in the AC method and 24% in the SSD method, although direct comparison is difficult because of different climatic conditions between the two years. Although visual selection is not considered to be accurate for quantitative traits such as yield-related traits, yield improvement was mainly achieved by selection, and not breeding method, in the cross used in this study.

AC and SSD are two important breeding methods to speed up the breeding cycle and to save labor and space. The

Table 3. Mean for yield and yield components of 45 selected lines and the top five high-yielding lines among AC and SSD populations.

Trait	45 selected lines		Best 5 lines	
	AC	SSD	AC	SSD
Days to heading	119 ± 7.3	121 ± 4.9	125 ± 5.0	128 ± 2.7
Culm length (cm)	75 ± 5.3	73 ± 4.4	84 ± 2.0	87 ± 3.0
Panicle length (cm)	23 ± 1.5	22 ± 1.3	26 ± 1.6	25 ± 0.7
Panicles plant^{-1} (no.)	15 ± 1.9	15 ± 1.9	18 ± 0.7	16 ± 1.2
Spikelets panicle^{-1} (no.)	151 ± 30.2	152 ± 39.4	179 ± 15.6	175 ± 15.8
Fertility (%)	82.0 ± 9.1	80 ± 11.7	95.3 ± 0.9	96 ± 0.7
1,000-grain weight (g)	22.3 ± 1.3	22 ± 1.5	22.3 ± 0.9	22.1 ± 1.0
Yield plant^{-1} (g)	36 ± 28.3	36 ± 24.5	44 ± 2.4	44 ± 2.5

AC method certainly has a clear time-saving advantage over the SSD method. In this study, it took only 4.5 years from crossing to a yield trial, whereas SSD took 6 years. However, for overall agronomic performance, including yield-related traits and rice quality, the AC and SSD methods were similar in terms of genetic variation, appearance of transgressive lines, and agronomic performance of selected breeding lines. In this context, anther culture can also be effectively used in a breeding program. In this experiment, only one cross was used. Therefore, more extensive and diverse research is necessary to understand the breeding efficiency of anther culture.

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Notes

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Advances in breeding salt-tolerant rice varieties

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Major progress has been made in breeding salt-tolerant high-yielding rice varieties for various inland saline, coastal saline, and alkaline soils of fragile ecosystems. Of 32 salt-tolerant rice varieties developed by the Central Soil Salinity Research Institute (CSSRI), CSR10 was the first dwarf high-yielding salt-tolerant early-maturing rice variety released. Varieties CSR10 and CSR11 are popular as biological amendments for resource-poor farmers. CSR13 is a fine-grain salt-tolerant rice variety adapted to alkaline and inland saline soils and CSR27 possesses dual tolerance of coastal salinity and sodicity. Both varieties have been released across India. CSR27 possesses high tissue tolerance and high K^+ and phosphorus-mining ability. We have successfully induced basmati qualities along with salt tolerance in CSR30, the first export-quality basmati rice. It has long slender, highly scented grains with good head rice recovery, high kernel elongation on cooking, intermediate gelatinizing temperature, and intermediate amylose content. A wide spectrum of rice germplasm (indigenous and exotic) has been evaluated and categorized for tissue tolerance, Na^+ exclusion, K^+ and P uptake, and reproductive-stage tolerance. We have combined different physiological mechanisms into one genetic background and these progenies show increased mining of P, K, and Zn and enhanced salt tolerance. However, no single physiological mechanism was found to be responsible for absolute salt tolerance. No correlation was observed for vegetative-stage salinity score with reproductive-stage salinity score and grain yield. Both additive and nonadditive gene effects for salinity tolerance, K^+, and Na^+/K^+ ratio have been detected. Varieties CSR10, CSR1, CSR13, and CSR 27 were the best combiners for salinity and alkalinity tolerance and related traits.