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# Genetics of Self-fertility and Selection of Self-Fertile Lines in Rye (*Secale cereale* L.)

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**ABSTRACT : Rye breeding using $F_1$ hybrid began about 30 years ago, when cytoplasmically inherited forms of male sterility (CMS) and corresponding nuclear restorers were detected. It is very important to produce inbred lines for making hybrid lines because of strong self-incompatibility in rye. Among the 456 rye germplasms used in hybrid breeding scheme, 24 lines (5.3%) had the above 60% of self-fertility, and six lines of them were selected for their good agronomic characteristics and were used for subsequent inbreeding program. The average self-fertility of selected six lines was 78.4%, ranging from 72.2 to 99.5%. Genetic analysis for the self-fertility using $F_2$ populations showed that the segregation of self-fertile and sterile plants in $F_2$ populations could be fit into 3 to 1 ratio suggesting self-fertility in rye be controlled by one major gene. The four different self-fertile lines, PI237923, 5C11, 5G5 and Florida black, had the same self-fertility gene because their $F_2$ plants showed almost the same self-fertility as their parents and showed no genetic segregation.**

***Keywords*** : rye, self-fertility, germplasm, genetic analysis, hybrid

A central problem in hybrid breeding program in rye is to evaluate the inbred lines for their performance in $F_1$ combinations. In heterozygous plants, successive inbreeding converts them to homozygosity (Williams, 1964) and the occurrence of defective recessive homozygous genes causes several detrimental effects. Inbreeding depression can be defined as loss of vigor in offspring which result from bouts of inbreeding, i.e. selfing or sib matings, for instance in small and genetically drifted populations, compared with randomly mated families. The occurrence of agronomically unfavorit recessive genes was studied by Bianchi (1965). But Briggs and Knowles (1967) reported the plant height was not changed after the inbreeding minimum was reached in the 5th year.

In rye, as in other cross-fertilized crops, a strong relationship exists between performance and degree of heterozygosity (Brewbaker, 1926; Duckart, 1928; Geiger & Wahle, 1978; Wricke, 1973).

Lundquist (1956) studied that self-fertilization is prevented by an effective gametophytic incompatibility mechanism in rye. The self-incompatibility can completely be offset by self-fertility genes which are now available in various materials and are extensively being used for the development of inbred lines in hybrid breeding. He also reported self-incompatibility was controlled by multiple alleles at each of two loci. Self-fertility may be caused by a single dominant gene, but frequently follows a more complex pattern of inheritance (Wricke, 1969; Zdril'ko & Derevyanko, 1979). Heat treatment during anthesis induces pseudo-compatibility in most self-incompatible genotypes, and by this method, average seed set may be increased up to 25% (Wricke, 1979).

## MATERIALS AND METHODS

### Screening of germplasm for self-fertility

Four hundred and fifty six germplasms of rye were obtained from Genetic Resources Division, National Seed Management Office and were screened for self-fertility. Ten seeds of each germplam were sown in September 24, 1991 in rows of 40 cm with 2 m length, at the upland experimental field of National Crop Experiment Station, Suwon, Korea.

Five spikes per plant were chosen and each spike was covered with paper bag to induce selfing at 7 days after heading. Two weeks after isolation, the paper bags were removed to prevent spikes from contamination of fungi. The ratio of seed set was recorded on a individual plant basis. The heading date, culm length and spike length were also recorded.

### Introduction of self-fertility into Korean open-pollinated cultivars

To introduce self-fertility genes into superior genetic background of Korean open-pollinated cultivars, six elite self-fertile lines were selected from foreign germplasms (Table 1) and seven leading open-pollinated Korean culti-

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vars (Paldanghomil, Chilbohomil, Jangganghomil, Chunchuhomil, Jochunhomil, Koolgrazer and Homil 22) were chosen. They were vernalized at 4°C for six weeks and transplanted to the pot with 15 cm diameter and a volume of approximately 1.9 L, in glass house in October 8, 1992. The open-pollinated lines, as female parents, were crossed with six different self-fertile lines in the controlled glass house. The $F_1$ plants were selfed for subsequent five generations in a glass house for generation advancement, along with selection pressure desirable agronomic traits such as early heading, long spike etc.

### Genetic analysis of self-fertility

To study the inheritance of self-fertility, two self-fertile lines, Synthetic II and PI237923 and one non-self fertile line, Chilbohomil, were used. The parents were vernalized for six weeks and transplanted in the pot to flowering stage in glass house in October 8, 1992. Chilbohomil, as a female parent, was crossed with two different self-fertile lines in the controlled glass house.

The $P_1$, $P_2$, $F_1$ and $F_2$ were grown in winter season of 1994/1995 in polyethylene film house at Suwon, and evaluated for self-fertility. Three spikes per plant were put in each isolation paper bag at 3 days after heading for 3 weeks to ensure selfing. The seed set was recorded on a plant basis, and segregation pattern of self-fertility in $F_2$ populations. Four different self-fertile lines, PI237923, 5C11, 5G5 and Florida black, were crossed to a non self-fertile line, Synthetic II, as a female parents.

From each cross, the $P_1$, $P_2$, $F_1$, and $F_2$ generations were established and grown in the same way mentioned above. The seed-set was investigated on a individual plant basis. The similarity of self-fertility gene in different self-fertile lines was also studied using $F_2$ segregating populations.

## RESULTS AND DISCUSSION

### Screening of rye germplasms for self-fertility

The distribution of major agronomic characteristics, heading date, culm length and spike length in introduced 456 rye germplasms were shown in Fig. 1. Comparing with Paldanghomil, the introduced rye germplasms had delayed heading date and longer culm length, but the most of germplasms had same spike length. This results suggested rye germplasms were diverged genetically from cultivated variety and could be utilized for rye improvement.

Among 456 germplasms, the number of germplasm which had below 1% of self-fertility was 122 (Fig. 2). And

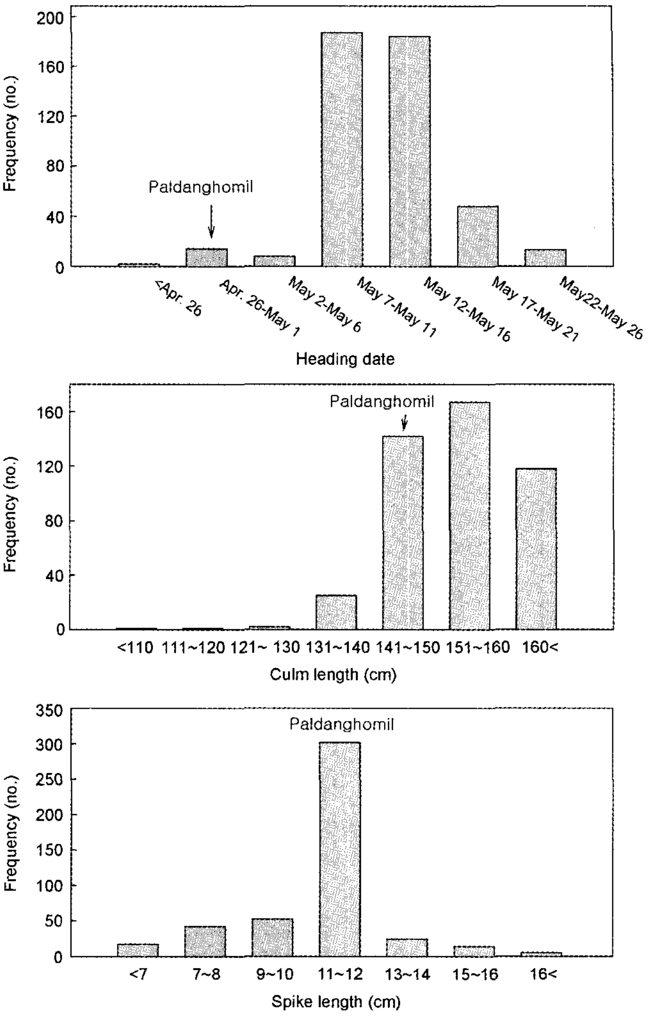

**Fig. 1.** Distribution of heading date, culm length and spike length in 456 rye germplasms.

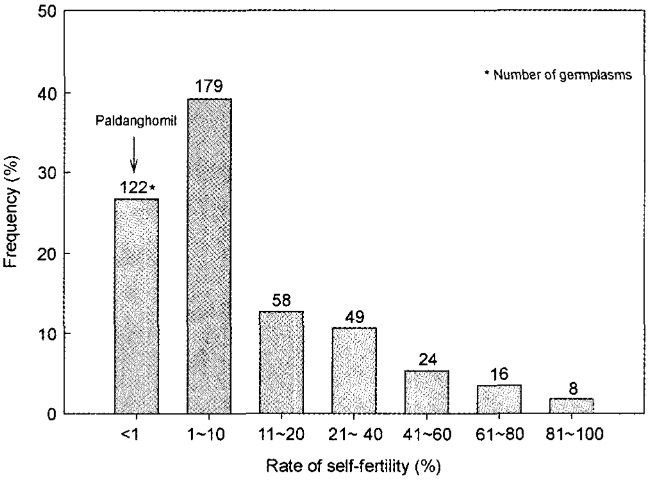

**Fig. 2.** Distribution of self-fertility in 456 rye germplasms.

the frequency of germplasms having below 10% of self-fertility was 66%. The number of rye lines with above 60% of self-fertility was only 24 lines (5.3%). Among 24 lines, six lines which had good agronomic traits, were selected for inbreeding program (Table 1). The average self-fertility of six selected lines was 78.4%, ranging from 72.2 to 99.5 with the heading date of May 12 in average which was twelve days later than the check variety 'Paldanghomil'.

### Development of inbred lines with genetic background of Korean elite cultivars

As a results of breeding activity to transfer self-fertile genes of foreign germplasm into Korean elite open-pollinated cultivars, fourteen inbred lines were developed after successive selfing for 5 generations. The donor parents for self-fertile genes were 5C11, 5G5, Synthetic II and Synthetic V. The major agronomic characters of selected inbred lines were shown in Table 2. The average self-fertility was 79%, which was higher than original non-fertile, open-pollinating female parents. The culm length reduced by 8cm, which seemed to be useful traits for $F_1$ seed production and lodging resistance. Spike length and number of grain per spike of these inbred lines were superior than original female parents.

**Table 1.** Major agronomic characteristics of selected self-fertile germplasms for inbreeding program.

| Germplasm | Rate of self-fertility (%) | Heading date | Culm length (cm) | Spike length (cm) | No. of† kernels (spike⁻¹) |
|---|---|---|---|---|---|
| 5C11 | 80.4 | May 9 | 145 | 11.4 | 52 |
| 5G5 | 73.5 | May 14 | 144 | 10.8 | 52 |
| Florida black | 72.7 | May 15 | 151 | 9.7 | 44 |
| PI237923 | 84.0 | May 12 | 135 | 10.4 | 46 |
| Synthetic | 72.2 | May 10 | 147 | 12.7 | 62 |
| Synthetic | 99.5 | May 12 | 150 | 13.4 | 78 |
| Average | 78.4 | May 12 | 145 | 11.4 | 56 |
| Paldanghomil (Check variety) | 0.3 | April. 30 | 147 | 10.2 | 46 |

†Number of kernel was counted after self-pollination using paper bag and that of check variety was based on open-pollination.

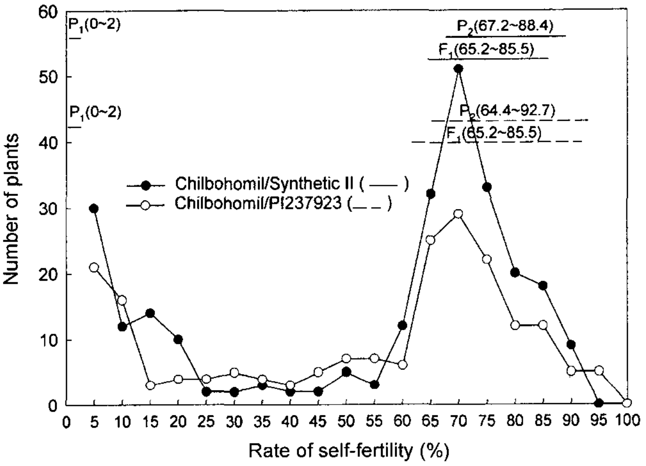

**Fig. 3.** Distribution of self-fertility in $F_2$ populations from crosses of Chilbohomil/Synthetic II and Chilbohomil/PI1237923.

**Table 2.** Major agronomic characteristics of fourteen inbred lines selected from breeding activity to transfer self-fertility into Korean elite cultivar.

| Inbred line | Cross combination | Self fertility (%) | Heading date | Culm length (cm) | Spike length (cm) | No. of† kernel (spike⁻¹) |
|---|---|---|---|---|---|---|
| SF1 | Paldanghomil/5C11 | 78 | May 2 | 141 | 10.7 | 42 |
| SF2 | Paldanghomil/Synthetic V | 87 | May 3 | 143 | 14.2 | 68 |
| SF3 | Chilbohomil/Synthetic II | 74 | May 2 | 145 | 12.2 | 48 |
| SF4 | Chilbohomil/Synthetic V | 88 | May 4 | 136 | 14.8 | 70 |
| SF5 | Jangganghomil/5C11 | 78 | May 5 | 140 | 11.4 | 44 |
| SF6 | Chunchuhomil/5G5 | 77 | May 5 | 142 | 11.4 | 46 |
| SF7 | Jochunhomil/5C11 | 77 | May 1 | 144 | 9.7 | 42 |
| SF8 | Jochunhomil/5G5 | 73 | May 3 | 138 | 9.2 | 42 |
| SF9 | Jochunhomil/Synthetic II | 68 | May 3 | 137 | 12.4 | 48 |
| SF10 | Jochunhomil/Synthetic V | 84 | May 4 | 135 | 15.1 | 72 |
| SF11 | Koolgrazer/Synthetic V | 82 | May 7 | 131 | 14.1 | 68 |
| SF12 | Koolgrazer/5C11 | 78 | May 6 | 142 | 12.2 | 50 |
| SF13 | Homil 22/Synthetic V | 85 | May 6 | 138 | 14.4 | 70 |
| SF14 | Homil 22/5C11 | 77 | May 6 | 140 | 8.9 | 42 |
|  | Average | 79 | May 4 | 139 | 12.2 | 54 |
|  | MD‡ | +77.4 | +1 | -8 | +1.7 | +7 |

†Number of kernel was counted after self-pollination using paper bag and that of female parents was based on open-pollination
‡Mean difference from the average values of female parents.

**Table 3.** Segregation for self-fertility in $F_2$ populations from the crossses of a non self-fertile line, Chilbohomil, and self-fertile lines, Synthetic II and PI237923, respectively.

| Cross combination | Number of plant for self-fertility[†] | | | Expected ratio | Segregating point | $\chi^2$ | P |
|---|---|---|---|---|---|---|---|
| | Fertile | non fertile | Total | | | | |
| Chilbohomil × Synthetic II | 175 | 66 | 241 | 3 : 1 | 25 | 0.732 | 0.25-0.50 |
| Chilbohomil × PI237923 | 110 | 37 | 147 | 3 : 1 | 15 | 0.001 | 0.90-0.95 |

[†] The $F_2$ plants with 30 to 50% of fertility from the cross of Chilbohomil and Synthetic II and those of 20 to 55% from Chilbohomil and PI237929 were not indicated in this data.

**Table 4.** Segregation pattern for self-fertility in $F_2$ populations crossed from the crosses of four different self-fertile lines.

| Cross combination | Number of plant for self-fertility | | | | |
|---|---|---|---|---|---|
| | 51-60% | 61-70% | 71-80% | 81-90% | 91-100% |
| Synthetic II × PI237923 | 4 | 96 | 95 | 18 | 1 |
| Synthetic II × 5C11 | 1 | 105 | 37 | 16 | 0 |
| Synthetic II × 5G5 | 11 | 72 | 75 | 28 | 1 |
| Synthetic II × Florida black | 12 | 92 | 36 | 3 | 0 |

## Genetic analysis of self-fertility

In the crosses of a non-self fertile line, Chilbohomil, and two self fertile lines, Synthetic II and PI237923, the $F_1$ plants showed similar level of self-fertility with the self-fertile parents, indicating the self-fertility was dominant. Bimodal distributions for self-fertility were observed in both $F_2$ populations, suggesting the major genes were involved in controlling the self-fertility (Fig. 3). Table 3 shows the segregation pattern of self-fertility in $F_2$ populations. In the $F_2$ population of the cross, Chilbohomil × Synthetic II, the number of plants over 55% of self-fertility and that of below 25% were 175 and 66 plants, respectively, which fitted into 3 to 1 ratios by chi-square test. In case of $F_2$ population of the cross, Chilbohomil × PI237923, the number of plants with above 60% and below 15% of self-fertility were 110 and 37 and giving monogenic segregation. From the results of $F_1$ and $F_2$ generation, the self-fertility from the donor parents, Synthetic II and PI237923, was controlled by one dorminant gene.

In the crosses between self-fertile donor parents such as Synthetic II × (PI237923, 5C11, 5G5, and Florida black), their $F_2$ plants showed almost the same self-fertility as their parents, showing similar segregation patterns (Table 4). From this result, it was concluded that the four different self-fertile lines might have the identical self-fertility gene.

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