Korean J. Crop Sci. 47(1): 29~35(2002)

Shattering-related Characteristics and Germination Speed Based on Grain Type and Esterase Isozyme Zymogram in Korean Off-rype Rice

Dong Kwan Kim*†, Il Doo Jin, Yeon Gyu Kim***, Kyung Soo Min****, Byung Gwan Jung**, and Yong Jae Kim******

**Jeonnam ARES, Naju 520-715, Korea*
***Coll. of Agric. and Life Sciences, Sunchon Nat'l. Univ., Sunchon 540-742, Korea*
****National Crop Experiment Station, RDA. Iksan 570-080, Korea*
*****Coll. of Agric., Chonnam Nat'l. Univ., Kwangju 500-757, Korea*

ABSTRACT : This study was carried out to investigate the characteristics of shattering habit and germination of off-type rice plants collected in Korea which were classified into seven groups based on grain characteristics. In the long-grain red rice group, the short-grain red rice group, the long-grain normal rice group, and the long-grain waxy rice group, the tensile strength of grain and primary rachis branch was relatively low and the fiber cell of the primary rachis branch was short. Characteristics of shattering-related traits and germination in relation to grain and esterase isozyme zymogram type of off-type rice plants. In most lines of the extremely late and sterile rice group, the tensile strength of grain was low, while that of primary rachis branch was high, and the fiber cell was long. However, in the type 1 esterase isozyme zymogram(EIZ) lines among the long-grain normal rice group and the type 6 and 5+6 EIZ plants among the extremely late and sterile rice group, the tensile strength of grain was relatively higher. The long-grain waxy rice group and the type 3 EIZ lines among the long-grain red rice group, showed higher germinability than did cultivars which are known to germinate well even in low-temperature. The other off-type rice group, except for the short-grain waxy rice group and type 1 and 7 EIZ lines among the long-grain normal rice group, had higher germination speed than that of the cultivars.

Keywords : rice, off-type, shattering habit, fiber cell, germination, esterase, isozyme

As the Japonica type rice cultivars have been planted and the direct-sowing paddy area increased, the off-type rice plants have emerged as one of the major weeds since the late 1980s in rice fields. Because the red rice among the off-type rice plants has a easier shattering habit compared to the cultivated ones, grains frequently shattered before full-ripe. Such characteristics are similar to weeds in general (Diarra *et al.*, 1985; Dunand, 1988; Kim, 1989; Pons *et al.*, 1995; Ree *et al.*, 1983; Smith, 1981). Kwon and Shin (1983) reported that as the tensile strength of the grain lessens, the loss from shattering increases when harvesting with a binder. The tensile strength without any shattering loss is approximately over 1.7N. Lim *et al.* (1990) reported that tensile strength and the anti-flex strength of the grain of domestic red rice type are similar to those of foreign red rice types but weaker than the Tongil type or Japonica type. Especially, the long-grain red rice type and most lines called Share had very weak tensile strength and anti-flex strength in the grains. Park (1990) reported that as for the Tongil type, the tensile strength of the grain, the tensile strength of the primary rachis branch, and the length of the fiber cell were lower than those of the Japonica type. He also found that the abscission layer shattering, the primary rachis branch shattering, and the anti-flex strength of the grain had a positive correlation, while the tensile strength of primary rachis branch, the length of the fiber cell, and the tensile strength of the grain had a negative correlation.

Red rice has gone through a gradual process of degeneration compared to 8 major weeds including Bull paspalum (*Paspalum boscianum*), or corn, bean and cultivated rice plants under winter flood conditions (Nelms & Twedt, 1996). In some cases, as there are dormant seeds lasting for 10 years buried in soil, red rice has a high possibility of being generated by shattering (Cohn & Hughes, 1981).

Kang *et al.* (1995; 1997) reported that the differences in low-temperature germinability among Japonica types showed notable when they were treated at 13°C for 11 days. There was a significant correlation between the coefficients of low-temperature germinability at 13°C at constant room temperature and an emergence coefficient in the drying field by the direct sowing method. In case of red rice, the rapid speed of germination and emergence can be the main competitive elements for in cultivated rice field (Clavijo & Baker, 1986). In case of early sow-

†Corresponding author: (Phone) +82-61-330-2663 (E-mail) dkkim@chonnam.rda.go.kr <Received July 18, 2001>

ing, the cultivated rice plant had a lower emergence percentage than when it was sown at the appropriate time, while the red rice had a similar emergence percentage regardless of sowing time (Kwon *et al.*, 1996). It also germinated rapidly (Diarra *et al.,* 1985). Song *et al.* (1992) reported that through examination of the activity of shattered seeds during wintertime, the germination percentage and germination speed were reduced as the time in the fields was lengthened.

In this study, classified were the off-type rice plants into 7 categories according to the characteristics of the seeds. We then investigated the tensile strength of the grain and primary rachis branch, the length and width of the primary rachis branch fiber cell, the low-temperature germinability, and the germination speed among the factors that were supposed to be related to occurrence by shattering.

MATERIALS AND METHODS

We classified the off-type rice plants that were collected in the farmers, field in 1997 into seven groups according to the characteristics of the seeds, as follows: the long-grain red rice group, the long-grain normal rice group, the long-grain waxy rice group, the short-grain red rice group, the short-grain normal rice group, the short-grain waxy rice group and the extremely late and sterile rice group. The extremely late and sterile rice group maintained green leaves even in yellow-ripe stage and ripened slowly, or showed a high panicle sterility. Then, we measured the tensile strength of the grain and primary rachis branch and the length and width of the primary rachis branch fiber cell.

In 1998, we cultivated a total of 64 lines of off-type rice plants; that is, each 10 lines of the long-grain red rice group, the short-grain red rice group, the short-grain normal rice group, and the short-grain waxy rice group; 13 lines of the long-grain normal rice group; 3 lines of the long-grain waxy rice group; and 8 lines of the extremely late and sterile rice group.

We sowed the seeds on May 5 and transplanted them one by one on June 4 in the trial field at an interval of 30 cm×15 cm. As for the extremely late and sterile rice group, we transplanted them 50 per line and as for the other off-type rice plant groups and the control group (Dongjinbyeo), we transplanted them 10 per line. We followed the Standard Act for Rice Plant Cultivation of Jeonnam Agricultural Research & Extension Services for other planting methods. For comparison, we selected Dasanbyeo, and Namcheonbyeo that had weak low-temperature germinability and Keumobyeo, Unbongbyeo, and Dongjinbyeo that had strong low-temperature germinability as the control groups and compared their germination properties.

We cut out the primary rachis branch and measured 50 grains per line with the tensile strength measuring machine (MD-2000, Shinkoh) to determine the tensile strength of the grain. To find the tensile strength of primary rachis branch, we measured a total of 20 primary rachis branch per line with the tensile strength measuring instrument at the 2.5 cm inside from the apex part of the primary rachis branch.

To know the length and width of a primary rachis branch fiber cell, we cut out the primary rachis branch by 1 cm per grain and measured 20 with the cellulose dissociative method. As the length of the fiber cells were so diverse, we selected middle-sized fiber cells among the full grown fiber cells and measured the length of 50 fiber cells and calculated their average value.

The seeds selected for investigating low-temperature germinability and germination speed were disinfected in a 2,000 times solution of prochloraz 25% (EC) for 24 hours after 75 days from harvest and then seed selection with salt solution. Then, we put filter paper (No. 2) on a plastic petri dish of 9 cm in diameter and put the seeds on the filter paper. In order to achieve low-temperature germinability, we put them at 13°C for 11 days and calculated the number of germinated grains. Also, to get the desired germination speed, we put them at 25°C for 5 days.

Esterase isoenzyme electrophoresis was conducted according to the method of Nakagahra (1977). For dyeing, 1% α & β naphtyl acetate was reacted at 37°C in the wet thermostat for 30 minutes and dyed in a 2% fast blue B salt solution. Electrophoresis types were analyzed based on the esterase isozyme zymogram (EIZ) of Nakagahra (1977) as shown in Fig. 1.

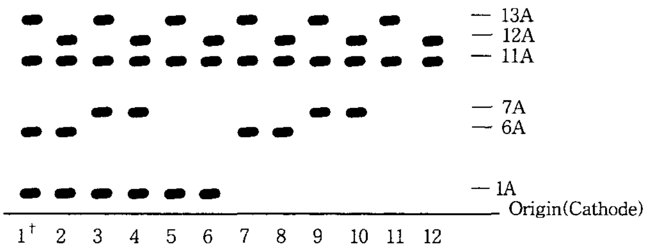

Fig. 1. All expected type of esterase isozyme zymogram (Nakagahra, 1977).
†1. $EST_1EST_2^SEST_3^F$(1A-6A-13A), 2. $EST_1EST_2^SEST_3^S$(1A-6A-12A), 3. $EST_1EST_2^FEST_3^F$(1A-7A-13A), 4. $EST_1EST_2^F$-EST_3^S(1A-7A-12A), 5. $EST_1EST_2^OEST_3^F$(1A-13A), 6. EST_1-$EST_2^OEST_3^S$(1A-12A), 7. $EST_1^OEST_2^SEST_3^F$(6A-13A), 8. $EST_1^OEST_2^SEST_3^S$(6A-12A), 9. $EST_1^OEST_2^FEST_3^F$(7A-13A), 10. $EST_1^OEST_2^FEST_3^S$(7A-12A), 11. $EST_1^OEST_2^OEST_3^F$ (13A only), 12. $EST_1^OEST_2^OEST_3^S$(12A only).

RESULT AND DISCUSSION

Tensile strength of grain

Grain tensile strength of the off-type rice plant groups and based on morphological classification

The tensile strength of the grain, which was considered to be directly related to the occurrence of the weedy rice plant, was investigated in relation to grain type. Generally, the off-type rice plant group that belonged to the long grain type had weaker tensile strength than the off-type rice plant group that belonged to the short grain type according to the frequency distribution shown in Table 1. The long-grain red rice group and the long-grain waxy rice group were mostly distributed in the category of lower tensile strength. The short-grain waxy rice group and the short-grain red rice group were distributed similar to the rice plant that was cultivated at a nearby site at the time of collection. The range of grain tensile strength of the long-grain normal rice group, the short-grain normal rice group, and the extremely late and sterile rice group were wide.

Comparing the shattering habit of the long-grain red rice group with that of the short-grain red rice group, the results were similar to the research results of Suh *et al.* (1992). In Suh's study, it was reported that long grain red rice shattered easily, while in the short grain red rice, only 14.8% were normally shattered.

Grain tensile strength of the type of esterase electrophoresis

Because off-type rice that was collected in farmer's paddy field at the same time had different ripening degree by plant, the tensile strength of the grain was not distinguishable. Therefore, we conducted genetic marker analysis for each line of the off-type rice plant group through esterase isoenzyme electrophoresis and measured the tensile strength of the grain on the same field condition next year.

Purebred off-type rice plant group

The results of esterase isoenzyme analysis, type 1 and 3 EIZ in Fig. 1, were shown in the long-grain red rice group and the long-grain normal rice group. Type 1+2 EIZ (hybrid type) was shown in the long-grain waxy rice group. Type 6 EIZ was represented in the short-grain off-type rice plant group and in the control group for comparison (Dongjinbyeo). Type 7 EIZ was represented in the long-grain normal rice group. As the tensile strength of the long-grain type was relatively lower than the Dongjinbyeo or short-grain off-

Table 2. Grain tensile strength of off-type rice plants collected in Korea.

EIZ†	Off type and cultivar‡	Grain tensile strength (g)	No. of tested plants
1	I	77.1 ± 15.4 bc	2
	II	116.3 ± 17.1 ab	5
3	I	67.1 ± 8.9 c	8
	II	78.0 ± 8.8 bc	3
1+2	III	56.1 ± 11.9 c	3
6	IV	79.0 ± 18.7 bc	10
	V	118.6 ± 56.1 ab	10
	VI	144.6 ± 37.0 a	10
7	II	84.9 ± 10.2 bc	5
6	Cultivar (Dongjinbyeo)	93.4 ± 13.7 b	-

L.S.D.(5%) 41.0
C.V.(%) 31.1
†See fig. 1, ‡See Table 1.

Table 1. Distribution of grain tensile strength of off-type rice plants collected in farmer's paddy field at harvest in Korea, 1997.

Off-type†	Grain tensile strength (g)									No. of tested plants	Mean
	~30	31~50	51~80	81~110	111~140	141~170	171~200	201~230	231~		
	Distribution (%)										
I	1.7	41.9	46.6	9.8						234	55 ± 15.9
II	4.1	27.3	47.1	11.6	5.0	2.5	0.8	0.8	0.8	121	69 ± 35.6
III	33.3	66.7								3	37 ± 7.3
IV		1.2	30.0	33.8	13.8	17.5	3.7			80	104 ± 35.5
V	1.5	3.0	15.1	19.5	15.8	21.8	9.8	9.0	4.5	113	128 ± 57.7
VI			5.8	17.3	13.5	23.1	23.1	11.5	5.8	52	154 ± 48.1
VII	10.4	25.7	20.3	11.9	10.4	7.4	5.5	6.4	2.0	202	91 ± 60.5
Cul.			16.6	16.7	26.7	26.7	3.3	10.0		30	131 ± 44.4

†I: Long-grain red, II: Long-grain normal, III: Long-grain waxy, IV: Short-grain red, V: Short-grain normal, VI: Short-grain waxy, VII: Extremely late and sterile, Cul. Cultivated varieties of surveyed fields.

Table 3. Grain tensile strength of segregating off-type rice plant lines (extremely late sterility) collected in Korea.

Line no.	Grain tensile strength (g)												
	~20	21~40	41~60	61~80	81~100	101~120	121~140	141~160	161~180	181~200	201~220	No. of tested plants	Mean
	Distribution (%)												
1		14.0	28.0	20.0	18.0	10.0	4.0	4.0	2.0			50	73.3 ± 33.8
2	2.1	20.8	27.1	16.7	16.7	2.1	4.2	8.4	2.1			48	72.1 ± 37.7
3					6.1	10.2	26.5	22.4	12.2	16.4	6.1	49	149.0 ± 31.8
4	4.3	17.4	17.4	23.9	19.6	8.6	6.5	2.2				47	70.2 ± 31.7
5	8.0	16.0	20.0	22.0	20.0	8.0	4.0	2.0				50	65.5 ± 32.9
6	2.0	20.4	18.4	24.5	20.4	12.3	2.0					50	67.8 ± 27.7
7	6.0	26.0	32.0	20.0	8.0	4.0		4.0				50	54.8 ± 29.5
8	8.0	18.0	22.0	24.0	18.0	8.0	2.0					50	64.5 ± 32.5
Cul.†				22.2	55.5	22.3						10	93.4 ± 13.7

†Cultivar : Dongjinbyeo.

type rice plant group, the long-grain type was found to be shattered easily. The electrophoresis type, long-grain groups, belongs to types 1, 3, 7, and 1+2 EIZ (Table 2). However, those of which the EIZ type was type 1 among the long-grain normal rice group turned out to have a similar shattering habit to that of Dongjinbyeo. Among the short-grain off-type rice plant groups of which the EIZ were all in type 6, the short-grain red rice group was more easily shattered than Dongjinbyeo group that had relatively easy shatter habits as the control group for the short-grain type. Therefore, there was no direct correlation between the EIZ types and shattering habits. On the other hand, considering the result that the long-grain normal rice group had a wide range of tensile strength as shown in Table 1, the long-grain normal rice group consisted of relatively diverse genetic properties other than those found in the long-grain groups. Overall, this result was similar to the research that reported that the long-grain red rice group had a better shattering habit than the short-grain red rice group had (Lim *et al.*, 1990).

If the tensile strength of the grain is strong, harvesting loss by machine is low (Kwon & Shin, 1983). Therefore, the long-grain normal rice group in type 1 EIZ, the short-grain normal rice group in type 6 EIZ, and the short-grain waxy rice group were expected to have a lower possibility of occurrence by shattering. Considering the research of Kim *et al.* (2001) that studied the occurrence of the off-type rice plant group according to the characteristics of the forms, the short-grain normal rice group and the short-grain waxy rice group experienced little occurrence, which was similar to the expected results.

Segregating off-type rice plant group (extremely late and sterile rice group)

The tensile strength of the grain in the extremely late and sterile rice group (Table 3), revealed that only line number 3 was higher among the selected 8 lines and was higher than that of the Dongjinbyeo, the control cultivar. The other 7 lines had 54.8~73.3 g of tensile strength, which were in general, lower than that of Dongjinbyeo.

The genetic marker of each off-type plant were analyzed by esterase isozyme electrophoresis and the tensile strength of the grain was measured (Table 4). The tensile strength of the subjects that belonged to type 6 EIZ and a crossbreed type 5+6 EIZ were high and similar to the results in Table 2. The off-type plants of type 8 EIZ proved to have higher tensile strength than the Dongjinbyeo. The subject was not found in the off-type rice plant group that was classified as purebred. The subject represented by type 5+6 EIZ among the hybrid EIZ had high tensile strength, while the subjects that showed type 1+2 and type 7+8 EIZ had low tensile strength.

Table 4. Grain tensile strength by esterase isozyme genotypes of segregating off-type rice plant lines (extremely late and sterile) collected in Korea.

EIZ†	No. of tested plants	Grain tensile strength (g)
1	96	84.6 ± 53.7
2	68	81.7 ± 37.6
1+2	153	83.0 ± 48.7
5	16	89.6 ± 51.1
6	11	118.2 ± 50.9
5+6	28	113.5 ± 53.8
7	8	80.5 ± 30.4
8	1	119.4
7+8	12	47.5 ± 23.6
12	1	43.8
6‡	10	93.4 ± 13.7

†See fig. 1, ‡Cultivar : Dongjinbyeo.

Tensile strength of primary rachis branch and characteristics of fiber cells.

Tensile strength of primary rachis branch

The tensile strength of the primary rachis branch (Table 5) showed a similar tendency the distribution of grain tensile strength (in Table 1) except for the extremely late and sterile rice group. That is, generally, the long-grain off-type rice plant group had lower tensile strength than that of the short-grain off-type rice plant group. Though it is a short-grain off-type rice plant group, the shattering of the lower section is higher than that of the control cultivar. These could be the major elements, along with low tensile strength of the grain, for mixing the off-type rice plant by shattering.

Length and width of the primary rachis branch fiber cell

As for the length of the primary rachis branch fiber cell, the off-type rice plant group was shorter than that of the cultivated type on the nearby farm according to the frequency distribution as in Table 6. And, the length of the primary rachis branch fiber cell of the long-grain off-type rice plant group was relatively shorter than that of the short-grain off-type rice plant group. Especially, the long-grain waxy rice group that had low tensile strength (Table 1) was found to be shorter both in length and width (the primary rachis branch fiber cell) than those of the cultivars or other off-type rice plant group. However, there was little difference in the width of the fiber cell between the off-type rice plant groups and was similar to cultivars in nearby farms. Such results were similar to the research of Park (1990). Park reported that the tensile strength and the length of the fiber cell of the primary rachis branch, the Tongil type with the long grain type, was shorter and weaker than those of the Japonica type with the short grain type.

As shown in the above, considering the tensile strength of the grain and the primary rachis branch, as well as the length and width of the fiber cell, the off-type rice plant group that

Table 5. Distribution of breaking tensile strength in primary rachis branch by collected off-type rice plants in farmer's paddy field at harvest in Korea, 1997.

Off-type†	Breaking tensile strength of primary rachis branch (g)										
	~200	201~250	251~300	301~350	351~400	401~450	451~500	501~550	551~	No. of tested lines	Mean
	Distribution (%)										
I	11.6	39.1	27.5	14.5	4.4	2.9				69	256 ± 59
II		2.6	5.1	5.1	43.6	38.5	5.1			39	381 ± 53
III		33.3	33.3	33.4						3	277 ± 46
IV			14.3	11.1	14.3	46.0	14.3			28	396 ± 43
V				8.3	30.0	41.7	11.7	8.3		60	416 ± 47
VI				4.3	30.3	13.0	17.4	26.1	8.7	30	454 ± 64
VII					6.7	25.3	37.3	18.7	12.0	75	470 ± 63
Cul.						28.5	42.9	28.6		14	469 ± 29

†See table 1.

Table 6. Distribution of length and width of fiber cell on primary rachis branch by off-type rice plants collected in farmer's paddy field at harvest in Korea, 1997.

Off-type†	Length of fiber cell (μm)				Width of fiber cell (μm)			
	401~600	601~800	801~1,000	Mean	7.1~9.0	9.1~11.0	11.1~12.0	Mean
	Distribution (%)				Distribution (%)			
I	42.8	57.2		624 ± 152	14.3	71.4	14.3	9.7 ± 2.2
II	91.3	8.7		534 ± 127	30.4	69.6		9.5 ± 2.3
III	100.0			486 ± 49	66.7	33.3		8.9 ± 0.9
IV	57.1	42.9		591 ± 130	28.6	71.4		9.2 ± 1.4
V	29.4	70.6		652 ± 165	47.1	47.1	5.8	9.2 ± 2.9
VI		66.6	33.4	787 ± 208	22.2	66.7	11.1	9.9 ± 2.0
VII	17.9	50.0	32.1	720 ± 181	46.4	50.0	3.6	9.3 ± 2.0
Cul.		28.5	71.5	826 ± 94	28.6	71.4		9.6 ± 2.2

†See table 1.

possibility of occurrence by shattering. However, as for occurrence according to the off-type rice plant group (Kim *et al.*, 2001), the long-grain normal rice group, the long-grain waxy rice group, and the long-grain red rice group that were known to be shattered easily, were generated only in the southern areas such as Jeonnam, Jeonbuk and Kyongnam. On the other hand, the off-type rice plant group prevailed in the short-grain red rice group and extremely late and sterile rice group and was equally distributed throughout the nation. We thought it was because the Tongil type plant has been cultivated until comparatively lately than in the southern area than in other area. Therefore, it is difficult to identify the occurrence path by shattering according to tensile strength of the grain and primary rachis branch, and the characteristics of the primary rachis branch fiber cell.

Characteristics of Germination

We transplanted on the trial field 6 kinds of off-type rice plant groups excluding the extremely late and sterile rice group, 2 kinds of cultivars that had weak low-temperature germinability and 3 kinds of cultivars that had strong low-temperature germinability (Rural Development Administration, 1995; 1988; 1985). After harvesting them, we measured low-temperature germinability and germination speed (Table 7). The germination percentage at 13°C for 11 days were 87.0 ± 7.0% for the long-grain waxy rice group with type 1+2 EIZ, and 81.0 ± 18.7% for the long-grain red rice group with type 3 EIZ, respectively. Such figures were higher than those of cultivars that reported strong low-temperature germinability of 50.7 ± 9.3%. The germination percentage of the short-grain waxy rice group showing type 6 EIZ was lower than that of the cultivar with weak low-temperature germinability. The germination percentage of the off-type rice plant group according to other EIZ types was higher than the cultivar that had weak low-temperature germinability. But it was similar to or lower than that of the cultivar with strong low-temperature germinability.

As for the germination speed (25°C/5 days), the short-grain waxy rice group showing type 6 EIZ and the long-grain normal rice group with type 1 and 7 EIZ, showed 50.8 ± 31.5%, 68.4 ± 27.2%, and 69.4 ± 36.7%, respectively, which was similarly low to those of the cultivars. The differences between lines were high. Other off-type rice plant groups showed 94.4~99.3%, which had a better germination speed than other cultivars had.

From such results, the long-grain waxy rice group and the long-grain red rice group with type 3 EIZ showed more possibilities of occurrence at low temperatures or could be germinated more quickly at the proper temperature in case of shattering in the farmer's paddy field. We also thought that long-grain waxy rice group as well as the red rice that Suh and Ha (1993) reported, has genetic characteristics useful to direct sowing cultivation.

Table 7. Germination speed of weedy rice plants collected in Korea and cultivars rice under incubation of temperature treatment.

EIZ[†]	Off-type and cultivars	Germination speed (%)	
		13°C/11 days	25°C/5 days
1	I[‡]	30.0 ± 8.0 bc	99.0 ± 1.0 a
	II	44.0 ± 36.0 abc	68.4 ± 27.2 ab
3	I	81.0 ± 18.7 ab	99.0 ± 1.4 a
	II	45.3 ± 22.2 abc	99.3 ± 0.9 a
1+2	III	87.0 ± 7.0 a	95.0 ± 5.0 a
6	IV	39.0 ± 36.2 abc	94.4 ± 3.3 a
	V	54.0 ± 31.3 abc	95.3 ± 6.3 a
	VI	13.0 ± 26.9 c	50.8 ± 31.5 b
7	II	44.0 ± 25.9 abc	69.4 ± 36.7 ab
	Cultivars		
1	LGALT[§]	1.3 ± 1.9 c	44.3 ± 5.2 b
6	HGALT	50.7 ± 9.3 abc	45.0 ± 0.8 b
L.S.D.(5%)		45.4	29.2
C.V.(%)		66.8	23.9

[†]See fig. 1, [‡]See table 1, [§]LGALT : Low germination ability at low temperature (Dasanbyeo, Namcheonbyeo), HGALT : High germination ability at low temperature (Keumobyeo, Unbongbyeo, Dongjinbyeo).

REFERENCES

Clavijo, J. and J. B. Baker. 1986. Early development of red rice and four rice cultivars. Proceeding, Southern Weed Science Society, *39th Annual Meeting* 478.

Cohn, M. A. and J. A. Hughes. 1981. Seed dormancy in red rice (*Oryza sativa*) I. Effect of temperature on dry-afterripening. *Weed Sci.* 29 : 402-404.

Diarra, A., R. J. Simth, and R. E. Talbert. 1985. Growth and morphological characteristics of red rice (*Oryza sativa*) biotypes. *Weed Sci.* 33 : 310-314.

Dunand, R. T. 1988. Red rice-Its impact on grain quality and its cultural control : A review of research in Louisiana, 1960-1982. *Bulletin, Louisiana Agricultural Experiment Station* 792 : 18pp.

Kang, J. R., M. S. Ko, H. Y. Kim, S. J. Lim, and S. C. Kim. 1997. Genetic analysis of low temperature germinability of rice. *Korean J. Crop Sci.* 42 : 766-777.

Kang, J. R., S. J. Lim, S. C. Kim, and M. S. Ko. 1995. Effective screening condition for low-temperature germinability of rice. *Korean J. Crop Sci.* 40 : 711-715.

Kim, D. K., I. D. Jin, D. S. Song, Y. J. Kim. 2001. Occurrences and characteristics of the off-type rice plant in farmer's paddy field. *Korean J. Crop Sci.* 46(3) : 170-175.

Kim, J. C. 1989. Physio-ecological characteristics of red rice (local name "Salebyeo", *Oryza sativa* L.) spontaneously occurring in

Korea and its competition with cultivated rice (*Oryza sativa* L.) 1. Germinative morphological and growing characteristics and dry mattter productive ability of red rice. *Res. Rept. RDA(R)* 31 : 34-52.

Kwon, Y. W., B. W. Lee, and D. S. Kim. 1996. Seedling-emergence of rice, weedy rice and *Echinochloa* species sown before wintering and in the early spring. *Kor. J. Weed. Sci.* 16 : 88-99.

Kwon, Y. W. and J. C. Shin. 1983. Shattering grain loss in relation to the impulse during harvest and year-variation of grain tensile strength in rice. *Korean J. Crop Sci.* 28 : 419-424.

Lim, W. J., K. K. Choi, and I. D. Jin. 1990. Relationship between degree of grain shedding and histological peculiarities of abcision region of red rice (*Oryza sativa* L.) collected in Korea. *Korean J. Crop Sci.* 35 : 239-247.

Nakagahra, M. 1977. Genic analysis for esterase isoenzymes in rice cultivars. *Japan. J. Breed.* 27 : 141-148.

Nelms, C. O. and D. J. Twedt. 1996. Seed deterioration in flooded agricultural fields during winter. *Wildlife Society Bull.* 24 : 85-88.

Rural Development Administration. 1995. Result of seed a conference of major the crops. pp. 27-123.

Rural Development Administration. 1988. Result of seed a conference of major the crops. pp. 35-56.

Rural Development Administration. 1985. Result of seed a conference of major the crops. pp. 43-54.

Park, J. Y. 1990. Relationship between grain shedding habit and pedicel strength of japonica-indica hybrid rices in Korea. MS. Thesis. Sunchon Univ. 37pp.

Pons, L., J. Recasens, F. Oliva, A. Taberner, and F. Riba. 1995. Red rice (*Oryza sativa* L.) a morphological description in Delta del Ebro (Tarragona, Spain). *Proceedings of the 1995 Congress of the Spanish Weed Science Society* 67-72.

Ree, D. W., Y. K. Hong, J. C. Kim, and Y. H. Kim. 1983. Ecological characteristics of red rice (local name "Sare", *Oryza sativa* L.) and factors affecting its competition with rice. *Kor. J. Weed Sci.* 3 : 143-150.

Smith, R. J. 1981. Control of red rice (*Oryza sativa*) in water-seeded rice (*O. sativa*). *Weed Sci.* 29 : 663-666.

Song, Y. J., Y. R. Kwon, N. K. Oh, B. R. Ko, C. J. Hwang, and G. H. Park. 1992. Germinability during over-wintering, field emergence and growth of shattered rice seeds on paddy field. *Korean J. Crop Sci.* 37 : 37-44.

Suh, H. S., S. Z. Park, and M. H. Heu. 1992. Collection and evaluation of Korean red rices I. Regional Distribution and seed characteristics. *Korean J. Crop Sci.* 37 : 425-430.

Suh, H. S. and W. G. Ha. 1993. Collection and evaluation of Korean red rices V. Germination characteristics on different water and soil depth. *Korean J. Crop Sci.* 38 : 128-133.