Diallel Cross Experiment among Sikkimese Varieties, Indica and Japonica Testers of Rice, *Oryza sativa* L.

I. Crossability, Pollen and Seed Fertilities

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INTRODUCTION

KATO *et al.* (1930)[11] proposed to divide *Oryza sativa* L. into two sub-species, *japonica* and *indica*. TERAO *et al.* (1944)[27] showed that the *javanica* varieties showed a very high affinity with Japanese varieties. These three major-groups are generally recognized by many workers. However, the idea of dividing rice varieties into geographical races is rapidly losing its significance in accordance with further intensive works (CHANG, 1964[1]). Moreover, hybridization by breeders has made some confusions in the classification scheme.

The generally accepted origin of *O. sativa* is the area embracing South Asia, Southeast Asia and China (ROSCHEVICZ, 1931[22] and others). MORINAGA (1967)[17] stated that Himalaya is an indigenous centre of rice. KIHARA *et al.* (1964)[12] and KATAYAMA[7,8,9] held that Sikkim might be one of the differentiation centres of *O. sativa* into *japonica* and *indica*, and moreover RAMIAH *et al.* (1951)[21] and KATAYAMA (1970)[10] stated that cultivated rice had been originated in south India and north India, respectively, and *japonica* type must have been developed later from *indica* type.

Classification and determination of indigenous centre of rice have been loomed upon as complex symptoms as mentioned above. In order to confirm the classification of rice varieties, especially Sikkimese rice, and to clarify the relationships between its strains and the types of typical *indica* and *japonica*, diallel crosses were carried out using 16 strains, that is, fourteen Sikkimese rice, one type of *indica* and another one type of *japonica*. In this report, three main characters, *i.e.*, crossability, pollen and seed fertilities and some relationships among three were described. Other about 30 characters, including morphological characters of plant, growing period, grain morphology, were measured and are going to be published in the future papers.

MATERIALS AND METHOD

Fourteen strains of Sikkimese rice varieties were picked up from 68 strains collected at Sikkim in 1959[13], and used in this experiment. One strain of *indica* and another one strain of *japonica* were also used as a tester. They are listed up and classified in Table 1. In this table, code No., strain No., origin, variety name, phenol reaction, pollen

Table 1. Materials used in the diallel cross experiment, variety name, origin, phenol reaction, pollen and seed fertilities obtained in the self pollinations.

Code No.	Strain No.	Origin	Variety	Phenol reaction	Pollen fertility (%)	Seed fertility (%)
1	108	Formosa	Indica	+	98.60	69.74
2	563	Japan	Japonica	−	96.52	77.47
3	C7707	Sikkim	Addey	+	81.64	95.31
4	C7716	〃	Lama	+	93.10	85.34
5	C7717	〃	Lama	+	95.57	52.98
6	C7718	〃	Tokmor Zo	+	94.29	91.32
7	C7719	〃	Tokmor Zo	+	97.60	25.95
8	C7722	〃	Addey	+	92.34	69.03
9	C7725	〃	Addey	+	86.31	85.98
10	C7727	〃	Addey	+, −	93.90	81.68
11	C7729	〃	Addey	+	96.78	86.94
12	C7732	〃	Tapachini	+	95.56	76.20
13	C7734	〃	Fudangay	+	95.53	74.53
14	C7735	〃	Fudangay	+	95.98	66.88
15	C7754	〃	Champasari	+	67.17	77.19
16	C7757	〃	Addey	−	92.32	88.03

and seed fertilities obtained in the self pollination are illustrated. These were sown in an air-conditioned greenhouse, and crosses being made there. For crosses, emasculation was made by a hot water method (43°C for 7 minutes). Combinations were attempted for 16 self pollinations and 240 cross pollinations, including reciprocals, whole of them being carried out successively during two seasons. Crosses were repeatedly continued for a while at the time when hybrid seeds counting more than 10 grains were obtained in the respective combination.

Hybrid and pure line seeds were sterilized with 0.1 % Uspulun solution, hydroxy-mercurichlorophenol, for 4 to 6 hours. They were washed twice by sterilized water and placed on moist filter paper in Petri-dishes and incubated at 30°C for germination. After 2-3 days after germination, young seedlings were planted in wooden boxes and kept in an upland condition. More than 10 seedlings of each F_1 hybrid and each parent were transplanted to the flooded concrete beds in single-plant hills at a spacing of 25 cm × 30 cm between plants, forming rows. The beds were constructed in an air-conditioned greenhouse. All F_1 and parent seeds were sown on May 1st and seedlings were transplanted on June 16th. During the experimental seasons, attention was paid to keeping suitable conditions for healthy growth of plants of different hybrids according to their symptoms and aspects. For example, weak-strawed plants were individually supported with stakes and string to prevent them from lodging.

In determining crossability, the value was indicated by the percentage of the succeeded individuals to the number of the pollinated florets. In order to examine pollen fertility, anthers were collected from a floret just flowering or one day before flowering. Up to 10 F_1 plants of each combination and 10 plants of each parent were rated for fertility.

All the six anthers from an apparently normal floret of each plant were used to make a slide mount for microscopic observation. Three countings of pollen grains more than 500 each were made from different areas of the mount. The pollen grains observed were stained in iodine-potassium iodine solution by ordinary method. The pollens which were stained dark blue with iodine were functional while those that remained unstained were not. Pollen-fertility-count was recorded as the percentage of the pollen grains stained to the whole pollen grains counted.

In determining seed fertility, panicles of the F_1 and of the parental plants were used. The panicle on the main culm of each plant was harvested and placed in a separate envelop shortly before full maturity, to minimize shattering. The number of spikelets on the panicle and the number of grains were used to calculate the percentage of seed set. The spikelets fertilized obviously were rated as fertile. Seed fertility count was recorded as the percentage of the well-developed grains to the whole spikelets counted.

RESULTS

I. Crossability

Success of pollination may be indicated by the percentage of the succeeded individuals to the number of the pollinated florets.

i) *Parent;* The data mentioned here were shown from the experiment, in which artificial pollination was made by own pollen grains which were after emasculation, but not bagged. The highest success (99.21 %) was obtained in No.2, followed by No.1 (97.52 %) and No.11 (96.94 %). The lowest success (90.32 %) was noted in No.15. Average and standard deviation of the whole strains were found as 94.24 ± 4.38. It may be said that the whole parents used here are to be looked upon as a pure line, showing a uniform pattern in regard to self pollination-ability. The degree of self pollination-ability was approximately the same within each sample. The values compared favorably with those observed in the rice grown under field conditions. In view of self pollination-ability no complete variety-specificity was to be ascertained. The ascertainment of which may be the chief character in the following cross experiment.

ii) *Hybrid;* The results of crossability among diallel crosses are shown in Table 2. A wide range of crossability was observed. Crossabilities for individual plant level ranged from 1 to 97 percent and the mean crossabilities ranged from 15 to 40 percent. In the combination level, the highest success (93.33 %) was obtained in the combination, No. 4 (♀) × No.2 (♂), followed by No.6 × No.15 (81.82 %) and No.2 × No.10 (80.00 %). The counting numbers of these pollinated florets were 15, 22 and 45, and those of the hybrid seeds obtained were 14, 18 and 36, respectively. The lowest success (1.30 %) was noted in the combination, No.11 × No.4, followed by No.12 × No.13 (1.31 %) and No.15 × No.3 (1.35 %). The numbers of these pollinated florets were 921, 762 and 740, and those of the hybrid seeds obtained were 12, 10 and 10, respectively. The differences of crossability were confirmed to be very large in accordance with each set of combination. The number of pollinated florets in view of the whole combinations made and that of the hybrid seeds obtained were 13,113 and 2,478, respectively.

In Table 3, the average value and the standard deviations of crossability in the

Table 2. Crossabilities of F_1 hybrid in percentage.

♀ Code No. \ ♂ Code No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		78.13	41.67	46.67	58.07	23.46	20.41	46.15	59.18	31.71	27.94	58.82	19.77	20.93	32.22	33.33
2	39.13		37.93	46.51	34.69	41.82	50.00	41.18	25.47	80.00	65.52	29.27	20.41	32.43	69.23	26.98
3	3.16	10.00		6.78	13.18	30.00	14.68	7.84	14.29	14.93	16.25	10.23	6.14	7.08	2.42	20.93
4	12.90	93.33	33.33		60.87	50.00	37.50	60.00	37.50	20.00	71.43	78.57	55.88	15.15	24.00	50.00
5	38.46	45.28	13.43	24.39		5.56	12.00	46.15	37.50	8.82	41.67	66.67	36.00	13.51	45.95	13.64
6	17.39	35.00	15.00	55.17	68.97		35.71	21.43	33.33	66.67	15.38	50.00	37.50	45.24	81.82	59.26
7	16.67	21.05	21.43	52.17	45.46	75.00		24.00	35.29	57.14	28.26	28.00	62.50	20.00	51.22	31.82
8	17.02	29.63	31.58	5.41	17.02	5.56	8.07		33.33	22.22	32.00	60.00	4.26	11.91	69.23	20.59
9	7.06	13.04	44.07	7.41	29.41	19.05	21.05	20.69		21.21	20.00	17.65	11.77	15.12	2.16	20.51
10	3.21	29.41	40.00	54.55	42.86	35.00	31.04	10.71	44.44		15.15	10.96	3.62	12.50	14.82	20.00
11	22.22	13.56	12.82	1.30	3.51	8.82	16.98	18.18	21.21	10.77		20.00	8.33	10.35	55.00	14.71
12	73.33	61.54	26.67	10.26	13.25	2.86	7.02	31.48	42.42	12.90	56.67		1.31	13.21	78.79	31.33
13	26.32	28.57	34.88	59.26	40.00	46.67	21.74	14.71	50.00	36.11	53.85	38.89		14.71	14.29	40.35
14	44.44	23.08	12.00	35.71	22.22	43.75	45.24	23.53	34.62	31.04	38.30	35.29	16.00		28.57	25.00
15	22.06	4.41	1.35	1.84	5.43	6.36	5.80	47.62	15.56	8.04	35.29	33.33	2.63	3.23		12.50
16	3.76	9.03	4.12	3.53	20.59	13.79	3.21	12.09	5.39	5.63	16.06	13.91	6.50	6.94	12.20	

Table 3. Averages and standard deviations of crossability, pollen and seed fertilities in female and male parent levels.

Code No.	Crossability ♀	Crossability ♂	Pollen fertility ♀	Pollen fertility ♂	Seed fertility ♀	Seed fertility ♂
1	39.87±17.03	23.07±18.42	80.80±15.11	77.13±11.85	47.40±14.84	55.93±13.87
2	42.73±16.61	33.00±25.31	65.27±17.92	85.40±11.48	50.47±19.27	38.33±21.93
3	11.80± 7.00	24.67±13.78	76.87±15.31	78.20±16.15	55.93±25.59	60.87±23.71
4	46.73±23.06	27.40±22.37	86.33± 6.86	84.07±11.64	65.53±15.99	67.20±11.06
5	30.07±17.53	31.73±19.94	84.27±10.45	83.53±12.68	65.07±13.03	58.20±17.55
6	42.67±20.45	27.33±20.47	82.80±11.00	85.53± 9.49	71.07±12.81	66.00±12.79
7	38.00±17.45	22.07±14.29	88.47± 7.55	84.53±10.44	50.67±18.48	51.07±25.01
8	24.53±18.54	28.47±15.49	82.20±14.89	72.13±17.93	49.47±20.71	65.33±16.10
9	18.00± 9.68	32.60±13.78	80.60±13.78	79.00±13.41	54.73±27.41	64.20±20.91
10	24.60±15.59	28.53±21.95	79.27±11.38	79.87±15.13	56.47±22.51	66.93±18.89
11	15.87±12.00	35.53±18.28	80.13±12.87	78.13±14.67	67.00±21.43	62.00±16.56
12	30.87±25.19	36.80±20.97	87.60± 9.75	87.80± 6.21	69.87±16.83	71.27±12.12
13	34.73±13.90	19.60±19.10	83.13±10.49	84.93±12.78	68.27±17.19	63.60±16.36
14	30.60± 9.86	16.13±10.15	67.33±35.52	80.07±15.91	54.13±19.61	48.87±25.66
15	13.67±13.97	38.73±26.76	76.53±15.53	69.47±16.61	56.00±22.07	39.67±23.39
16	9.20± 5.19	28.13±12.78	79.87±11.82	77.87±15.31	57.20±23.58	59.80±21.15
Whole	28.37±17.02		80.09±16.37		58.70±21.30	

whole combinations are shown. Each figure used in the table shows average and standard deviations in each parent when the strain was used as female and male parents, including 15 combinations each. In other words, the data ranked in the female row in Table 3 were horizontally calculated at the figures shown in Table 2, and the data ranked in the male row in Table 3 were longitudinally calculated at the figures shown in Table 2, respectively. In view of female parent, the highest value in parental average (46.73 %) was obtained in No.4, followed by No.2 (42.73 %) and No.6 (42.67 %). The lowest value in the parental average (9.20 %) was obtained in No.16, followed by No. 3 (11.80 %) and No.15 (13.67 %). The differences of crossability in the parental level were ascertained to be very large in accordance with each parent. In standard deviation, the highest value (25.19) was obtained in No.12, followed by No.4 (23.06) and No.6 (20.45). The lowest value (5.19) was noted in No.16, followed by No.3 (7.00) and No.9 (9.68). The relation between the values of average and standard deviations was not clearly recognized. In view of the male parent, the highest value in parental average (38.73 %) was obtained in No.15, followed by No.12 (36.80 %) and No.11 (35.53 %). The lowest value in parental average (16.13 %) was noted in No.14, followed by No.13 (19.60 %) and No.7 (22.07 %). In the standard deviation, the highest value (26.76) was also obtained in No.15, followed by No.2 (25.31) and No.4 (22.37). The lowest value (10.15) was also noted in No.14, followed by No.16 (12.78) and No.3 (13.78). The relation between values of average and standard deviations was also not clearly recognized, either. The average crossability and its standard deviation of the whole combinations were 28.37 ± 17.02.

In view of variety specificity, the following facts were ascertained. In the case of female parent, all strains of *indica*, *japonica*, Lama, Tokmor Zo, Tapachini and Fudangay varieties showed the values larger than that of the average in the whole combinations (= 28.37). On the other hand, all strains of Addey and Champasari varieties showed the values smaller than that of the average in the whole combinations. In the case of male parent, *japonica*, Tapachini and Champasari varieties showed the values larger than that of the average in the whole combinations. All strains of *indica*, Tokmor Zo and Fudangay varieties showed the values smaller than that of the average in the whole combinations. On the other hand, Addey and Lama varieties segregated for the values larger and smaller than that. Reciprocal differences were not clearly illustrated in the variety level in view of crossability, so far as the considerations made with the use of the data shown in Table 3 were concerned.

To make clear the crossability in view of reciprocal combinations, correlation coefficient and linear regression of crossability of female parent on male parent in the same strain were calculated and shown in Table 4. Basing on the data obtained in this calculation, T-test was made from analysis of variance for reciprocal cross comparisons. From this table, the following facts were ascertained. Only 1 strain showed negative significance, and the other 15 strains showed no significance even at 5 % level. In the whole strains, value meant no significant difference. It was concluded that reciprocal

Table 4. Correlation coefficient and linear regression of crossability of female parent (Y) on male parent (X). 0 points; 47.5 in both female and male parents.

Code No.	Correlation coefficient	d.f.	Linear regression
1	0. 3102	13	—
2	0. 1393	13	—
3	-0. 7979***	13	$Y=-0.452X-8.974$
4	0. 3684	13	—
5	-0. 4257	13	—
6	-0. 1371	13	—
7	-0. 0374	13	—
8	0. 3432	13	—
9	-0. 5083	13	—
10	0. 0232	13	—
11	-0. 3700	13	—
12	-0. 1181	13	—
13	0. 1179	13	—
14	0. 0148	13	—
15	-0. 0379	13	—
16	-0. 0173	13	—
Whole	-0. 0026	118	—

***; Significant at 0. 1 % level.

differences in this study did not suggested noteworthy cytoplasmic influence on the crossability.

The differences between the maximum and the minimum values of crossability for each parent in view of the female parent were as follows in the order from No.1 to No.16; 58.36, 59.59, 27.58, 70.43, 61.11, 66.82, 58.33, 64.97, 41.91, 51.34, 53.70, 77.48, 44.97, 33.24, 46.27 and 17.38, respectively. The average and standard deviations of these were 52.09±15.77. It may be noted that the value was peculiarly small in No.16, as it is the lowest average of this strain. The strain showing large value in this respect had remarkable difference in crossability found in the combinations with 15 alien parents, at the time when the strain was used as female parent and alien strains were used as male parents. In an extreme case, the crossabilities were 1.31 % and 78.79 % in No.12 × No.13 and No.12 × No.15, respectively. The former value was nearly the lowest in the whole combinations (=240). In other words, No.12 showed affinities remarkably different from each strain, at the time when it was used as female parent. The strain showing small value in this respect had a few differences in the crossability found in the combinations with 15 alien parents, at the time when the strain was used as female parent and alien strain were used as male parents. In an extreme case, the crossabilities were 20.59 % and 3.21 % in No.16 × No.5 and No.16 × No.7, respectively. In other words, No.16 showed affinities relatively similar to each strain, at the time when it was used as female parent. Those values in view of the male parent were as follows in the order from No.1 to No.16; 70.17, 88.92, 42.72, 57.96, 65.46, 72.14, 46.79, 52.16, 53.79, 74.37, 56.28, 68.34, 61.19, 42.01, 79.66 and 46.76, respectively. The average and standard deviations of these were 61.17±13.36. The strain showing large value in this respect had remarkable difference in crossability found in the combinations with 15 alien parents, at the time when the strain was used as male parent and alien strains were used as female parents. In an extreme case, the crossabilities were 93.33 % and 4.41 % in No.4 × No.2 and No.15 × No.2, respectively. The former value was the largest in the whole combinations (=240). In other words, No.2 showed affinities remarkably different from each strain, at the time when No.2 was used as male parent. The strain showing small value in this respect had a few differences in the crossability found in the combinations with 15 alien parents, at the time when the strain was used as male parent and alien strains were used as female parents. In an extreme case, the crossabilities were 45.24 % and 3.23 % in No.6 × No.14 and No.15 × No. 14, respectively. In other words, No.14 showed the affinities relatively similar to each strain, at the time when No.14 was used as male parent. In reciprocal view, it was ascertained that correlation coefficient was +0.5096, showing significance at 5 % level, and that the larger was the differences in this respect at the time when the strain was used as female parent, the larger was the differences in this respect at the time when the strain was used as male parent.

In view of variety specificity, the following facts were ascertained. In the case of female parent, all strains of *indica*, *japonica*, Lama, Tokmor Zo, Tapachini and one third of Addey varieties showed the values larger than that of the average in the whole strains (=52.09). All strains of Fudangay and Champasari and two third of Addey varieties showed the values smaller than that of the average in the whole strains. In the case of male parent, *indica*, *japonica*, Tapachini and Champasari varieties showed the values larger than that of the average in the whole strains (=61.17). On the other hand, strains of Addey, Lama, Tokmor Zo and Fudangay varieties segregated for the values larger and smaller than that. Further relation in the reciprocal combination was not clearly ascertained.

To make clear the relations between Sikkimese rice and two testers, the differences of crossability at the time when two testers crossed with Sikkimese rice and reciprocals were calculated. In view of the female parent, the differences of crossability for *indica* (No.1) and *japonica* (No.2) were as follows in the order from No.3 to No.16, provided that the calculation was made only by the absolute values; 6.84, 80.43, 6.82, 17.61, 4.38, 12.61, 5.98, 26.20, 8.66, 11.79, 2.25, 21.36, 17.65 and 5.27, respectively. The strain showing large value in this respect had remarkable difference in the crossability found in the combinations with two testers, at the time when the strain was used as female parent and the testers were used as male parents. In an extreme case, the crossabilities were 12.90 % and 93.33 % in No.4×No.1 and No.4 × No.2, respectively. In other words, No.4 showed affinities remarkably different from each tester, at the time when No.4 was used as female parent. The strain showing small value in this respect had a few differences in the crossability found in the combinations with two testers, at the time when the strain was used as female parent and the testers were used as male parents. In an extreme case, the crossabilities were 26.32 % and 28.57 % in No.13×No.1 and No.13×No.2, respectively. In other words, No.13 showed affinities similar to each tester, at the time when No.13 was used as female parent. Average and standard deviations of this value in the whole Sikkimese rice were 16.28±19.05. In view of the male parent, the differences of crossability for *indica* and *japonica* were as follows in the order from No.3 to No.16; 3.74, 0.16, 23.38, 18.36, 29.59, 4.96, 33.71, 48.29, 37.58, 29.55, 0.64, 11.50, 37.01 and 6.35, respectively. The strain showing large value in this respect had remarkable difference in the crossability found in the combinations with two testers, at the time when the strain was used as male parent and the testers were used as female parents. In an extreme case, the crossabilities were 31.71 % and 80.00 % in No.1 × No.10 and No.2×No. 10, respectively. In other words, No.10 showed affinities remarkably different from each tester. The strain showing small value in this respect had a few differences in the crossability found in the combinations with two testers, at the time when the strain was used as male parent and the testers were used as female parents. In an extreme case, the crossabilities were 46.67 % and 46.51 % in No.1×No.4 and No.2×No.4, respectively. In other words, No.4 showed affinities similar to each tester. Average and standard deviations of this value in the whole Sikkimese rice were 20.34±15.35.

It was noticeable that No.4 showed a large value in the crossability differences against each tester at the time when it was used as female parent, but showed a small value, when used as male parent. On the other hand, Nos.5, 7, 9, 11, 12 and 15 showed the large values in crossability differences against each tester when used as male parent, showing small values, when used as female parent. Nos.3, 13 and 16 showed relatively the small values in differences of crossability for each tester when they were used as both female and male parents. In reciprocal view, correlation coefficient between them was +0.0926, showing no significance even at 5 % level. Further relation in the reciprocal combination was not clearly ascertained.

In view of variety specificity, the following facts were ascertained. In the case of female parent, half of Lama, half of Tokmor Zo, one sixth of Addey, half of Fudangay and Champasari varieties showed the values larger than that of the average in the whole strains (=16.28). Five sixth of Addey, half of Lama, half of Tokmor Zo, half of Fudangay and Tapachini varieties showed the values smaller than that of the average in the whole strains. In the case of male parent, half of Addey, half of Lama, half of Tokmor Zo, Tapachini and Champasari varieties showed the values larger than that of the average in the whole strains (=20.34). Half of Addey, half of Lama, half of Tokmor Zo and Fudangay varieties showed the values smaller than that of the average in the whole strains.

II. Pollen fertility

Pollen fertility count was recorded as the percentage of the well-developed pollen grains to the whole pollen grains counted.

i) *Parent;* The pollen fertilities of parental plants are shown in Table 1. The highest (98.60 %) was obtained in No.1, followed by No.7 (97.60 %) and No.11 (96.78 %). The lowest (67.17 %) was noted in No.15, followed by No.3 (81.64 %) and No.9 (86.31 %). The value of No.15 was remarkably small. Average and standard deviations of the whole strains were found to be 92.08 ± 7.66. It may be said that the whole strains used here are looked upon as a pure line, showing the uniform pattern in regard to pollen fertility. Any variety specificity in view of pollen fertility was not found completely. The values compared favorably with those commonly observed in rice grown under field conditions. The ascertainment of this was the chief character for the following observations on the pollen fertility of the hybrid plants.

ii) *Hybrid;* The values of pollen fertility among diallel crosses are shown in Table 5. A range, which was wide but narrower than that of crossability, of pollen fertility was observed. Pollen fertilities for individual plant level ranged from 28 to 99 percent and the mean pollen fertilities ranged from 36 to 98 percent. In the combination level, the highest fertility (97.87 %) was obtained in case of the combination, No.14 (♀) × No. 6 (♂), followed by No.5 × No.14 (96.80 %) and No.6 × No.14 (96.50 %). The numbers of these pollen grains observed were 1,968, 2,188 and 2,229, and those of good pollen grains were 1,926, 2,118 and 2,151, respectively. The lowest fertility (39.49 %) was noted in the case of combination, No.15 × No.8, followed by No.8 × No.15 (40.75 %) and No.2 × No.8 (41.76 %). The numbers of these pollen grains observed were 2,173, 2,974 and 3,458, and those of good pollen grains were 858, 1,212 and 1,444, respectively. The differences of pollen fertility were confirmed to be considerably large in accordance with each combination. The numbers of the good pollen grains and that of the pollen grains observed in view of the whole combinations were 38,456 and 48,016, respectively.

In Table 3, the average value and standard deviations of pollen fertility in the whole combinations are shown. Each figure used in the table shows average and standard deviations in each parent, at the time when the strain was used as female and male parents, including 15 combinations each. In other words, the data ranked in female row in Table 3 were horizontally calculated at the figures shown in Table 5, and the data ranked in male row in Table 3 were longitudinally calculated at the figures shown in Table 5, respectively. In view of female parent, the highest value in parental average (88.47 %) was obtained in No.7, followed by No.12 (87.60 %) and No.4 (86.33 %).

Table 5. Pollen fertilities of F_1 hybrid in percentage.

♀ \ ♂ Code No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		79.23*	49.56*	89.18	95.68	95.89	86.30*	47.94*	68.52	68.75*	77.15	95.69	92.91	89.26	90.35	85.02
2	56.60*		55.02	53.62	85.21	80.71	63.40	41.76*	49.78*	44.41*	49.88*	73.65*	95.91	95.83	80.63*	51.41*
3	76.61*	52.47*		92.38*	65.75*	83.18*	60.84	86.12	93.38*	94.37	88.67	89.49	71.81*	45.57*	61.73*	90.95
4	83.45	95.43	76.99*		94.51	91.51	94.31	78.25	83.76	80.91*	79.61	93.32	89.34	93.76	83.02*	75.57
5	91.78	87.53*	67.37	92.63		91.45	91.91*	73.90*	65.44	75.83*	78.14*	90.02	96.49	96.80*	88.61	74.43*
6	93.10	95.24*	60.59*	93.17	94.17		92.72	68.75	74.91	71.15*	71.51	85.56	76.90	96.50	83.63*	82.33
7	77.01	93.99	88.59*	89.71	95.95	94.62		92.73*	70.09*	88.50*	90.84*	90.72*	94.26	93.51	76.12*	87.53*
8	55.84	93.25	90.43	92.51	89.51	83.78	91.71		85.38*	89.95	92.09	82.47	89.16	66.97	40.75	89.25
9	62.89	73.47*	93.86	86.19	65.46	62.24	91.98*	91.51		94.07	92.65	89.02	88.97	67.00	54.65	92.68
10	68.85*	72.47*	91.26	81.35	68.27*	69.90	82.27*	84.19	92.71		93.85	92.60	82.53	55.76	64.70	87.02
11	73.94	87.37*	93.58	71.72	77.38	84.27	91.09	88.40	90.54	88.24		76.29	89.28	66.09	42.43	83.33
12	94.19	94.53	87.67*	93.76	89.72	90.41	90.10	54.45	85.74	88.17	78.86		95.54	92.19	83.84	92.55
13	80.58	95.03	75.88	92.54	94.01	86.98	82.65	81.86*	92.51	85.19*	78.10	89.23		81.80	50.98	78.41*
14	86.55	93.78	52.99	89.76	95.57	97.87	93.28	60.60	56.56	49.29*	57.90	92.57	44.88		83.27*	42.96
15	82.38	84.57*	93.75	67.02	81.14	89.54	82.46	39.49	84.94	85.82	48.58	82.00	84.40	84.89		54.61
16	71.44	81.27	93.46	73.59	58.48	79.09	72.64	89.54	88.45	93.52	92.07	91.81	80.89	72.79	55.48	

*: Mixed the differently sized pollen grains.

The lowest value in parental average (65.27 %) was noted in No. 2, followed by No. 14 (67.33 %) and No.15 (76.53 %). The differences of pollen fertility in the parental level were ascertained to be very large in accordance with each parent. In standard deviation, the highest value (35.52) was obtained in No.14, followed by No.2 (17.92) and No.15 (15.53). The lowest value (6.86) was noted in No.4, followed by No.7 (7.55) and No.12 (9.75). The relation between values of average and standard deviations was not clearly recognized. In view of male parent, the highest value in parental average (87.80 %) was obtained in No.12, followed by No.6 (85.53 %) and No.2 (85.40 %). The lowest value in parental average (69.47 %) was noted in No.15, followed by No.8 (72.13 %) and No.1 (77.13 %). In the standard deviation, the highest value (17.93) was obtained in No.8, followed by No.15 (16.61) and No.3 (16.15). The lowest value (6.21) was noted in No.12, followed by No.6 (9.49) and No.7 (10.44). The relation between the values of average and standard deviations was not recognized clearly, either. The average pollen fertility and its standard deviation of the whole combinations were 80.09 ± 16.37.

In view of variety specificity, the following facts were ascertained. In the case of female parent, *indica*, Lama, Tokmor Zo, Tapachini, half of Fudangay and half of Addey varieties showed the values larger than that of average in the whole combinations (=80.09). On the other hand, *japonica*, Champasari, half of Fudangay and half of Addey varieties showed the values smaller than that of the average in the whole combinations. In case of male parent, *japonica*, Lama, Tokmor Zo, Tapachini and half of Fudangay varieties showed the values larger than that of the average in the whole combinations. On the other hand, *indica*, Addey, half of Fudangay and Champasari varieties showed the values smaller than that of the average in the whole combinations. Reciprocal differences were not clearly illustrated in the variety level in view of pollen fertility, so far as the considerations made using the data shown in Table 3 were concerned.

To make clear pollen fertility in view of reciprocal combinations, correlation coefficient and linear regression of pollen fertility of female parent on male parent in the same strain were calculated and shown in Table 6. Basing on the data obtained in this calculation, T-test was made from analysis of variance for reciprocal cross comparisons. From this table the following facts were ascertained. Three strains, 4 strains, 2 strains and 7 strains showed significances at 0.1 %, 1 %, 5 % levels and no significance even at 5 % level, respectively. In other words, about half of strains showed significance, and the other half showed no significance. In the whole strains, the value meant high significance at 0.1 % level. Pollen fertilities of hybrid, at the time when each strain was used as female parent, are shown in Table 7 in relation to the pollen fertility of hybrids at the time when respective strain was used as male parent. There is a strong positive correlation between them. Correlation coefficient is +0.5794 to the degree of freedom of 118, which is obviously significant at the 0.1 % level. Generally speaking, the higher is the pollen fertility at the time when strain was used as female parent, the higher is the pollen fertility at the time when strain was used as male parent. This finding was clearly different from that of crossability. It was concluded that reciprocal differences in this study did not suggested considerable cytoplasmic influence on the pollen fertility.

Table 6. Correlation coefficient and linear regression of pollen fertility of female parent (Y) on male parent (X). 0 points; 67.5 in both female and male parents.

Code No.	Correlation coefficient	d.f.	Linear regression
1	0.8587***	13	Y=1.018X+0.701
2	0.3287	13	—
3	0.6536**	13	Y=0.793X−0.265
4	0.0908	13	—
5	0.8444***	13	Y=0.780X+0.823
6	0.5661*	13	Y=0.558X+1.340
7	-0.1214	13	—
8	0.8323***	13	Y=0.597X+0.060
9	0.6148*	13	Y=0.710X+0.522
10	0.6601**	13	Y=0.790X+0.304
11	0.7129**	13	Y=0.818X+0.267
12	0.3514	13	—
13	0.3024	13	—
14	0.7341**	13	Y=0.696X+1.112
15	0.5054	13	—
16	0.4703	13	—
Whole	0.5794***	118	Y=0.684X+0.490

***, **, *; Significant at 0.1%, 1% and 5% levels, respectively.

The differences between the maximum and the minimum values of pollen fertilities for each parent in view of female parent were as follows in the order from No.1 to No.16; 47.95, 54.15, 48.80, 19.86, 31.36, 35.91, 25.86, 52.50, 39.42, 38.09, 51.15, 41.09, 44.05, 54.91, 54.27 and 38.04, respectively. The average and standard deviations of these were 42.34±10.25. These values were clearly smaller than that of crossability. It may be noted that the value was peculiarly small in No.4, basing on its having the high average of this strain. The strain showing large value in this respect had remarkable difference in pollen fertility found in the combinations with 15 alien parents, at the time when the strain was used as female parent and alien strains were used as male parents. In an extreme case, the pollen fertilities were 97.87% and 42.96% in No. 14 × No.6 and No.14 × No.16, respectively. In other words, No.14 showed affinities remarkably different from each strain, at the time when No.14 was used as female parent. The strain showing small value in this respect had a few differences in pollen fertility found in the combinations with 15 alien parents, at the time when the strain was used as female parent and alien strains were used as male parents. In an extreme case, the pollen fertilities were 95.43% and 75.57% in No.4 × No.2 and No.4 × No.16, respectively. In other words, No.4 showed affinities nearly similar to each strain, at the time when No.4 was used as female parent. Those in view of the male parent were as follows in the order from No.1 to No.16; 38.35, 42.96, 44.30, 40.14, 37.47, 35.63, 33.47, 53.25, 43.60, 49.96, 45.27, 22.04, 51.61, 51.23, 49.60 and 49.72, respectively.

Table 7. Pollen fertility of all F_1 hybrids in relation to the reciprocal combination. Figure used in the table shows the number of combinations.

Female parent (%)	Male parent (%)													Total
	100 ~ 96	95 ~ 91	90 ~ 86	85 ~ 81	80 ~ 76	75 ~ 71	70 ~ 66	65 ~ 61	60 ~ 56	55 ~ 51	50 ~ 46	45 ~ 41	40 ~ 36	
100~96	2	6	1											9
95~91	1	15	7	2	1									26
90~86		4	7	6	2	1								20
85~81		3	3	5	1	1	1	1		1		1		17
80~76		1	1	2	2	3	1		1					11
75~71		1	1	1	1		1	1	1					7
70~66		1		1			2	2	2					8
65~61		2	2				1							5
60~56											1			1
55~51		1		3					1	1				6
50~46			1		1	1			1	1				5
45~41		1				2					1			4
40~36													1	1
Total	3	35	23	20	8	8	6	4	6	3	2	1	1	120

$r=+0.5794^{***}$ (d.f.=118), significant at the 0.1 % level.

Those average and standard deviations were 43.04±8.05. Those values were clearly smaller than that of crossability. It may be noted that the value was peculiarly small in No.12, basing on its having the highest average of this strain. The strain showing large value in this respect had remarkable difference in pollen fertility found in the combinations with 15 alien parents, at the time when the strain was used as male parent and alien strains were used as female parents. In an extreme case, the pollen fertilities were 92.73 % and 39.48 % in No.7 × No.8 and No.15 × No.8, respectively. The latter value was the smallest in the whole combinations (=240). In other words, No.8 showed affinities remarkably different from respective strains, at the time when No.8 was used as male parent. The strain showing small value in this respect had a few differences in the pollen fertility found in the combinations with 15 alien parents, at the time when the strain was used as male parent and alien strains were used as female parents. In an extreme case, the pollen fertilities were 95.69 % and 73.65 % in No.1 × No.12 and No.2 × No.12, respectively. In other words, No.12 showed affinities relatively similar to each strain, at the time when No.12 was used as male parent. In reciprocal view, it was ascertained, in general, that the larger was the differences in this respect at the time when the strain was used as female parent, the larger was the differences in this respect at the time when the strain was used as male parent, but correlation coefficient between them was fixed to be +0.4475, showing no significance even at 5 % level.

In view of the variety specificity, the following facts were ascertained. In the case of female parent, *indica*, *japonica*, Fudangay, Champasari and half of Addey varieties showed the values larger than that of the average in the whole strains (=42.34). Lama, Tokmor Zo, Tapachini and half of Addey varieties showed the values smaller than that of the average in the whole strains. In the case of male parent, Addey, Fudangay and Champasari varieties showed the values larger than that of the average in the whole strains (=43.04). *Indica*, *japonica*, Lama, Tokmor Zo and Tapachini varieties showed the values smaller than that of the average in the whole strains. These findings propose a quite interesting problem concerning the strain or variety differentiations.

To make clear the relations between Sikkimese rice and two testers, the differences of pollen fertility at the time when two testers crossed with Sikkimese rice and reciprocals were calculated. In view of female parent, the differences of pollen fertility for *indica* (No.1) and *japonica* (No.2) were as follows in the order from No.3 to No.16, provided that the calculation was made only by the absolute values; 24.14, 11.98, 4.25, 2.14, 16.98, 37.41, 10.58, 3.62, 13.43, 0.34, 14.45, 7.23, 2.19 and 9.83, respectively. The strain showing large value in this respect had remarkable difference in the pollen fertility found in the combinations with two testers, at the time when the strain was used as female parent and the testers were used as male parents. In an extreme case, the pollen fertilities were 55.84 % and 93.25 % in No.8 × No.1 and No.8 × No.2, respectively. In other words, No.8 showed affinities remarkably different from each tester, at the time when No.8 was used as female parent. The strain showing small value in this respect had a few differences in the pollen fertility found in the combinations with two testers, at the time when the strain was used as female parent and the testers were used as male parents. In an extreme case, the pollen fertilities were 94.19 % and 94.53 % in No.12 × No.1 and No.12 × No.2, respectively. In other words, No.12 showed affinities quite similar to each tester, at the time when No.12 was used as female parent. Average and standard deviations of this value in the whole Sikkimese rice were 11.33±9.67. These values were clearly smaller than that of crossability. In view of male parent, the differences of pollen fertility for *indica* and *japonica* were as follows in the order from No.3 to No.16; 5.46, 35.56, 10.47, 15.18, 22.90, 6.18, 18.74, 24.34, 27.27, 22.04, 3.00, 6.57, 9.72 and 33.61, respectively. The strain showing large value in this respect had remarkable difference in the pollen fertility found in the combinations with two testers, at the time when the strain was used as male parent and the testers were used as female parents. In an extreme case, the pollen fertilities were 89.18 % and 53.62 % in No.1 × No.4 and No.2 × No.4, respectively. In other words, No.4 showed affinities remarkably different from each tester. The strain showing small value in this respect had a few differences in the pollen fertility found in the combinations with two testers, at the time when the strain was used as male parent and the testers were used as female parents. In an extreme case, the pollen fertilities were 92.91 % and 95.91 % in No.1 × No.13 and No.2 × No.13, respectively. In other words, No.13 showed the affinities similar to each tester. Average and standard deviations of this value in the whole Sikkimese rice were 17.22±10.34. These values were clearly smaller than that of crossability.

It was noted that Nos.3, 8 and 13 showed the large values in differences of pollen fertility against each tester, at the time when they were used as female parents, showing small values in differences of pollen fertility against each tester when used as male parent. On the other hand, Nos.4, 6, 10, 12 and 16 showed the small values in differences of pollen fertility to each tester, when used as female parent, showing large values in differences of pollen fertility for each tester, when used as male parent. Nos.7, 9 and 11 showed relatively the large values in differences of pollen fertility for each tester, both when used as female parent and when as male parent. Nos.5, 14 and 15 showed relatively the small values in differences of pollen fertility for each tester, both when used as female parent and when as male parent. In reciprocal view, correlation coefficient between them was -0.2928, showing no significance even at 5 % level.

In view of variety specificity, the following facts were ascertained. In the case of female parent, half of Addey, half of Lama, half of Tokmor Zo and half of Fudangay varieties showed the values larger than that of the average in the whole strains (= 11.33). Half of Addey, half of Lama, half of Tokmor Zo, half of Fudangay, Tapachini and Champasari varieties showed the values smaller than that of the average in the whole strains. In the case of male parent, two third of Addey, half of Lama, half of Tokmor Zo and Tapachini varieties showed the values larger than that of the average in the whole strains (=17.22). One third of Addey, half of Lama, half of Tokmor Zo, Fudangay and Champasari varieties showed the values smaller than that of the average in the whole strains.

III. Seed fertility

Seed fertility count was recorded as the percentage of the well-developed seeds to the whole seeds accounted.

i) *Parent;* The seed fertilities of parental plants are shown in Table 1. The highest (95.31 %) was obtained in No.3, followed by No.6 (91.32 %) and No.16 (88.03 %). The lowest (25.95 %) was noted in No.7, followed by No.5 (52.98 %) and No.14 (66.88 %). The value of No. 7 was remarkably small. Average and standard deviations of the whole strains were found as 75.29 ± 15.79. Average value was remarkably smaller than those of self pollination-ability and pollen fertility, and its standard deviation was remarkably larger than those of the former two characters. Excepting for No. 7, the values compared favorably with those commonly observed in the rice grown in field conditions.

ii) *Hybrid;* The values of seed fertility among diallel crosses are shown in Table 8. A wide range of seed fertility was observed and ascertained to be larger than that of pollen fertility. Seed fertilities for individual plant level ranged from 1 to 97 percent and the mean seed fertilities ranged from 10 to 90 percent. In the combination level, the highest fertility (95.36 %) was obtained in the combination, No.13 × No.6, followed by No.9 × No.3 (93.00 %) and No.11 × No.10 (92.95 %). The numbers of these seeds accounted were 409, 871 and 1,263, and those of the well-developed seeds were 390, 810 and 1,174, respectively. The lowest fertility (1.45 %) was noted in the combination, No.8 × No.2, followed by No.7 × No.15 (1.53 %) and No.15 × No.7 (2.48 %). The latter two combinations were in reciprocal relationships. The numbers

Table 8. Seed fertilities of F_1 hybrid in percentage.

♀ Code No. \ ♂ Code No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		58.50	48.47	51.89	66.20	53.58	20.28	35.10	39.95	38.70	45.40	70.99	30.54	36.25	73.77	39.48
2	38.57		23.05	60.76	62.30	65.90	64.11	42.82	65.68	23.65	21.05	62.75	73.13	59.87	72.08	19.46
3	65.60	10.17		83.61	43.40	55.86	24.56	67.55	71.19	85.86	75.70	83.46	51.93	8.94	31.84	76.51
4	48.89	64.92	36.47		65.45	58.75	84.00	82.01	79.43	73.81	40.03	72.79	89.21	71.77	43.04	71.44
5	57.98	59.08	85.11	78.55		69.77	69.14	73.46	74.32	50.29	73.44	74.05	70.00	60.92	40.29	40.12
6	65.94	61.79	82.96	74.45	55.17		86.68	68.78	80.75	63.62	61.22	61.34	84.73	87.71	45.34	83.95
7	29.72	49.85	45.63	59.29	59.16	76.08		63.01	33.44	61.05	47.90	39.75	62.38	77.43	1.53	53.54
8	54.14	1.45	53.50	58.72	42.79	66.07	39.44		52.66	74.75	69.12	81.32	40.43	41.98	12.84	53.28
9	50.60	12.23	93.00	53.81	36.08	43.40	61.75	62.00		88.72	82.61	75.37	55.28	7.65	12.29	85.47
10	45.89	10.54	77.62	67.00	48.51	69.28	17.08	72.89	86.63		65.98	68.30	64.87	27.40	44.44	79.73
11	41.85	16.88	72.74	61.48	62.59	63.99	69.92	89.25	88.16	92.95		84.46	72.57	70.69	29.52	85.25
12	78.70	54.51	86.42	74.81	90.47	47.66	44.95	77.14	76.09	75.77	80.59		75.50	30.45	87.11	65.14
13	72.50	48.27	70.29	90.38	84.36	95.36	73.33	56.83	61.32	69.90	68.89	79.30		67.94	20.78	65.80
14	49.67	56.39	30.27	71.48	65.32	79.22	64.94	77.01	19.26	52.61	72.20	55.63	68.22		28.38	22.01
15	78.44	45.44	24.39	55.74	70.94	78.94	2.48	33.51	45.51	62.42	54.52	87.56	75.32	69.01		54.35
16	57.92	23.83	82.24	63.17	19.90	66.15	42.97	77.19	89.07	87.80	71.41	71.14	39.53	14.44	52.30	

of these seeds accounted were 1,586, 2,152 and 888, and those of the well-developed seeds were 23, 33 and 22, respectively. The differences of seed fertility were confirmed to be considerably as large in accordance with each combination. The numbers of the well-developed seeds and those of the seeds accounted in view of the whole combinations were 146,943 and 250,328, respectively.

In Table, 3, the average value and the standard deviations of seed fertility in the whole combinations are shown. Each figure used in the table shows average and standard deviations in each parent, at the time when the strain was used as female and male parents, including 15 combinations each. In other words, the data ranked in female row in Table 3 were horizontally calculated at the figures shown in Table 8, and the data ranked in male row in Table 3 were longitudinally calculated at the figures shown in Table 8, respectively. In view of female parent, the highest value in parental average (71.07 %) was obtained in No.6, followed by No.12 (69.87 %) and No.13 (68.27 %). The lowest value in parental average (47.40 %) was noted in No.1, followed by No. 8 (49.47 %) and No.2 (50.47 %). The differences of seed fertility in the parental level were ascertained to be very large in accordance with each parent. In standard deviation, the highest value (27.41) was obtained in No.9, followed by No.3 (25.59) and No.16 (23.58). The lowest value (12.81) was noted in No.6, followed by No.5 (13.03) and No.1 (14.84). The relation between values of average and standard deviations was not clearly recognized. In view of male parent, the highest value in parental average (71.27 %) was obtained in No.12, which was the same as the pollen fertility in case of the female parent, followed by No.4 (67.20 %) and No.10 (66.93 %). The lowest value in parental average (38.33 %) was obtained in No.2, the same as the pollen fertility of female parent, followed by No.15 (39.67 %) and No.14 (48.87 %). In standard deviation, the highest value (25.66) was obtained in No.14, followed by No.7 (25.01) and No.3 (23.71). The lowest value (11.06) was noted in No.4, followed by No.12 (12.12) and No.6 (12.79). The relation between values of average and standard deviations was not clearly recognized, either. The average seed fertility and its standard deviation of the whole combinations were 58.70 ± 21.30.

In view of variety specificity, the following facts were ascertained. In the case of female parent, Lama, Tapachini, half of Tokmor Zo, one sixth of Addey and half of Fudangay varieties showed the values larger than that of average in the whole combinations (=58.70). On the other hand, *indica*, *japonica*, five sixth of Addey, half of Tokmor Zo, half of Fudangay and Champasari varieties showed the values smaller than that of the average in the whole combinations. In the case of male parent, Addey, half of Lama, half of Tokmor Zo, Tapachini and half of Fudangay varieties showed the values larger than that of the average in the whole combinations. On the other hand, *indica*, *japonica*, half of Lama, half of Tokmor Zo, half of Fudangay and Champasari varieties showed the values smaller than that of the average in the whole combinations. Reciprocal differences were not clearly illustrated in the variety level in view of seed fertility, so long as the considerations made with the use of data shown in Table 3 were concerned.

To make clear the seed fertility in view of the reciprocal combinations, correlation coefficient and linear regression of seed fertility of female parent on male parent in the same strain were calculated and shown in Table 9. Basing on the data obtained in this

Table 9. Correlation coefficient and linear regression of seed fertility of female parent (Y) on male parent (X). 0 points; 47.5 in both female and male parents.

Code No.	Correlation coefficient	d.f.	Linear regression
1	0.5531*	13	Y=0.584X−0.695
2	0.6907**	13	Y=0.643X−0.615
3	0.6515**	13	Y=0.651X+0.535
4	-0.0026	13	—
5	0.1662	13	—
6	0.6502**	13	Y=0.666X+1.424
7	0.6639**	13	Y=0.796X+0.708
8	0.4661	13	—
9	0.4844	13	—
10	0.7030**	13	Y=0.599X+0.670
11	0.7741***	13	Y=0.824X−0.453
12	0.7800***	13	Y=0.808X+0.214
13	0.2209	13	—
14	0.8083***	13	Y=1.007X−1.478
15	0.5348*	13	Y=0.546X+0.096
16	0.8095***	13	Y=0.722X+0.871
Whole	0.5797***	118	Y=0.583X+0.582

***, **, *; Significant at 0.1 %, 1 % and 5 % levels, respectively.

calculation, T-test was made from analysis of variance for reciprocal cross comparisons. From this table, the following facts were ascertained. Four strains, 5 strains, 2 strains and 5 strains showed significances at 0.1 %, 1 %, 5 % levels and no significance even at 5 % level, respectively. In other words, about three fourth strains showed significance, and one fourth strains showed no significance. In the whole strains, value meant high significance at 0.1 % level, which was about the same degree of pollen fertility. Seed fertilities of hybrid, at the time when each strain was used as female parent, are shown in Table 10 in relation to the seed fertility of hybrids, at the time when respective strain was used as male parent. There is apparently a strong positive correlation between them. Correlation coefficient is +0.5797 to the degree of freedom of 118, which is obviously significant at the 0.1 % level. Generally speaking, the higher is the seed fertility at the time when strain was used as female parent, the higher is the seed fertility at the time when strain was used as male parent. This finding was clearly different from that of crossability but the same as that obtained from pollen fertility. It was concluded that reciprocal differences in this study did not suggested special cytoplasmic influence on the seed fertility.

The differences between the maximum and the minimum values of seed fertilities for each parent in view of female parent were as follows in the order from No.1 to No. 16; 53.49, 53.67, 76.92, 52.74, 44.99, 42.37, 75.90, 79.87, 85.35, 76.09, 76.07, 60.02, 74.58, 59.96, 85.08 and 74.63, respectively. Those average and standard deviations were 66.98

Table 10. Seed fertility of all the F_1 hybrids in relation to the reciprocal combination. Figure used in the table shows the number of combinations.

Female parent (%)	Male parent (%)																			Total
	95~91	90~86	85~81	80~76	75~71	70~66	65~61	60~56	55~51	50~46	45~41	40~36	35~31	30~26	25~21	20~16	15~11	10~6	5~1	
90~86		4		3																7
85~81	1	2	1	1	1	1		2			1	1								11
80~76		1	1	1	1		1		1											6
75~71	2			3	4	2	2			1	2	1								17
70~66	1	1	1	2		2	1	2	2			1					1			14
65~61					2	2	3	1	1	2		1				1				13
60~56			1		1			1				1								4
55~51				1		2	2		1	1	1									8
50~46						2				1										3
45~41			1	2			1	1			1								1	7
40~36					1		1	2	1	2	1					1				9
35~31					1		1	1	1						1					5
30~26						1			2											3
25~21					1					1						1	2	1		6
20~16														1	1					2
15~11										1			1							2
10~ 6														1		1				2
5~ 1																			1	1
Total	4	8	5	13	12	12	12	10	9	9	6	5	1	2	2	4	3	1	2	120

$r=+0.5797^{***}$ (d.f.=118), significant at the 0.1 % level.

±13.79. The average value was clearly larger than those of crossability and pollen fertility, but the standard deviation was the middle value between that of crossability and pollen fertility. It may be noted that the value was peculiarly large in Nos.9 and 15. The strain showing large value in this respect had remarkable difference in seed fertility found in the combinations with 15 alien parents, at the time when the strain was used as female parent and alien strains were used as male parents. In an extreme case, the seed fertilities were 93.00 % and 7.65 % in No.9 × No.3 and No.9 × No. 14, respectively. In other words, No.9 showed affinities remarkably different from each strain, at the time when No.9 was used as female parent. The strain showing small value in this respect had a few differences in seed fertility found in the combinations with 15 alien parents, when the strain was used as female parent and alien strains were used as male parents. In an extreme case, the seed fertilities were 87.71 % and 45.34 % in No.6 × No.14 and No.6 × No.15, respectively. In other words, No.6 showed affinities relatively near to each strain, at the time when No.6 was used as female parent. Those in view of the male parent were as follows in the order from No.1 to No.16; 48.98, 63.47, 69.95, 38.49, 70.57, 51.96, 84.20, 55.74, 69.81, 69.30, 61.56, 47.81, 58.67, 80.06, 85.58 and 66.01, respectively. Those average and standard deviations were 63.89±12.90. The average was larger than that of crossability and pollen fertility, and the deviation was the same as that of crossability and larger than that of pollen fertility. It may be noted that the value was peculiarly small in No.4. Strain showing the largest (85.58 %) was found in No.15, which was the same as the one in case of female parent. The strain showing large value in this respect had remarkable difference in seed fertility found in the combinations with 15 alien parents, at the time when the strain was used as male parent and alien strains were used as female parents. In an extreme case, the seed fertilities were 1.53 % and 87.11 % in No.7 × No.15 and No. 12 × No.15, respectively. In other words, No.15 showed affinities remarkably different from each strain, at the time when No.15 was used male parent, as same as female parent. The strain showing small value in this respect had a few differences in the seed fertility found in the combinations with 15 alien parents, at the time when the strain was used as male parent and alien strains were used as female parents. In an extreme case, the seed fertilities were 51.89 % and 90.38 % in No.1 × No.4 and No.13 × No.4, respectively. In other words, No.4 showed affinities relatively near to each strain, at the time when No.4 was used as male parent. In reciprocal view, it was, in general, ascertained that the larger were the differences in this respect, at the time when the strain was used as female parent, the larger were the differences in this respect at the time when the strain was used as male parent, but correlation coefficient between them was +0.4427, showing no significance even at 5 % level.

In view of variety specificity, the following facts were ascertained. In the case of female parent, Addey, Champasari, half of Tokmor Zo and half of Fudangay varieties showed the values larger than that of the average in the whole strains (=66.98). *Indica*, *japonica*, Lama, half of Tokmor Zo, Tapachini and half of Fudangay varieties showed the values smaller than that of the average in the whole strains. In the case of male parent, half of Lama, half of Tokmor Zo, two third of Addey, half of Fudangay and Champasari varieties showed the values larger than that of the average in the whole strains (=63.89). *Indica*, *japonica*, half of Lama, half of Tokmor Zo, one third of Addey, half of Fudangay and Tapachini varieties showed the values smaller than that of the average in the whole strains. This findings propose interesting problem concerning the strain or variety differentiations.

To make clear the relations between Sikkimese rice and two testers, the differences of seed fertility at the time when two testers crossed with Sikkimese rice and reciprocals were calculated. In view of female parent, the differences of seed fertility for *indica* (No.1) and *japonica* (No.2) were as follows in the order from No.3 to No.16, provided that the calculation was made only by the absolute values; 55.43, 16.03, 1.10, 4.15, 20.13, 52.69, 38.37, 35.35, 24.97, 24.19, 24.23, 6.72, 33.00 and 34.09, respectively. The strain showing large value in this respect had remarkable difference in the seed fertility found in the combinations with two testers, at the time when the strain was used as female parent and the testers were used as male parents. In an extreme case, the seed fertilities were 65.60 % and 10.17 % in No.3 × No.1 and No.3 × No.2, respectively. In other words, No.3 showed affinities remarkably different from each tester, at the time when No.3 was used as female parent. The strain showing small value in this respect had a few differences in the seed fertility found in the combinations with two testers, at the time when the strain was used as female parent and the testers were used as male parents. In an extreme case, the seed fertilities were 57.98 % and 59.08 % in No.5 × No.1 and No.5 × No.2, respectively. In other words, No. 5 showed affinities quite similar to each tester, at the time when No.5 was used as female parent. Average and standard deviations of this value in the whole Sikkimese rice were 26.46±15.90. The average value was clearly larger than that of crossability and pollen fertility. Value of deviation was larger than that of pollen fertility but smaller than that of crossability. In view of male parent, the differences of seed fertility for *indica* and *japonica*, in the order from No.3 to No.16, were as follows; 25.42, 8.87, 3.90, 12.32, 43.83, 7.72, 25.73, 15.05, 24.35, 8.24, 42.59, 23.62, 1.69 and 20.02, respectively. The strain showing large value in this respect had remarkable difference in the seed fertility found in the combinations with two testers, at the time when the strain was used as male parent and the testers were used as female parents. In an extreme case, the seed fertilities were 20.28 % and 64.11 % in No.1 × No.7 and No. 2 × No.7, respectively. In other words, No.7 showed affinities remarkably different from each tester. The strain showing small value in this respect had a few differences in the seed fertility found in the combinations with two testers, at the time when the strain was used as male parent and the testers were used as female parents. In an extreme case, the seed fertilities were 73.77 % and 72.08 % in No.1 × No.15 and No. 2 × No.15, respectively. In other words, No.15 showed affinities quite similar to each tester. Average and standard deviation of this value in the whole Sikkimese rice were 18.81 ± 12.66. Those values were smaller than that of crossability and larger than that of pollen fertility.

It was noticeable that Nos.8, 12 and 15 showed the large values in seed fertility differences against each tester at the time when they were used as female parents, showing small values in that to each tester, when used as male parent. On the other hand, Nos.7, 13 and 14 showed the small values in differences of seed fertility against each tester, at the time when they were used as female parents, showing the large values in differences, when used as male parent. Nos.3, 9, 10, 11 and 16 showed relatively the large values in difference of seed fertility for each tester, both when used as the female and when used as the male parent. Nos.4, 5 and 6 showed relatively small values in differences of seed fertility to each tester, both when used as the female and when used as the male parent. In reciprocal view, it was, in general, ascertained that the larger were the differences in this respect at the time when the strain was used as female parent, the larger was the differences in this respect at the time when the strain was used as male parent, but correlation coefficient between them being +0.4374, showing no significance even at 5 % level.

In view of variety specificity, the following facts were ascertained. In the case of female parent, five sixth of Addey and Champasari varieties showed the values larger than that of the average in the whole strains (=26.46). One sixth of Addey, Lama, Tokmor Zo, Tapachini and Fudangay varieties showed the values smaller than that of the average in the whole strains. In the case of male parent, two third of Addey, half of Tokmor Zo and Fudangay varieties showed the values larger than that of the average in the whole strains (=18.81). One third of Addey, half of Tokmor Zo, Lama, Tapachini and Champasari varieties showed the values smaller than that of the average in the whole strains.

IV. Relations between three characters

Relations between crossability, pollen and seed fertilities were analyzed basing on correlation coefficient and linear regression calculated, and T-tests of the respective values were also made from analyses of variance for the respective character.

i) *Relation between crossability and pollen fertility;* To make clear relationship between crossability and pollen fertility, three kinds of calculation were made. Correlation coefficient and linear regression of crossability on pollen fertility are shown in Table 11, basing on strain level and the whole combinations, and T-tests were also made from analyses of variance for two characters. From this table the following facts were ascertained. Two strains, Nos.8 and 11, showed correlation coefficients as -0.4751 and -0.4869, respectively, and negative significances at 1 % level. The remaining fourteen strains and the whole combinations showed no significance even at 5 % level.

Table 11. Correlation coefficient and linear regression of pollen fertility (Y) on crossability (X). 0 points; 67.5 and 47.5 in pollen fertility and crossability, respectively.

Code No.	Correlation coefficient	d.f.	Linear regression
1	0. 1769	28	—
2	-0. 1516	28	—
3	-0. 0156	28	—
4	0. 2263	28	—
5	0. 2534	28	—
6	0. 2217	28	—
7	0. 1372	28	—
8	-0. 4751**	28	Y=—0. 508X—0. 383
9	0. 0863	28	—
10	0. 0107	28	—
11	-0. 4869**	28	Y=—0. 377X+0. 563
12	0. 1896	28	—
13	0. 2118	28	—
14	0. 2867	28	—
15	-0. 1200	28	—
16	0. 0323	28	—
Whole	-0. 0108	238	—

** ; Significant at 1 % level.

The differences between the maximum and the minimum values of crossability and the pollen fertility of each parent were calculated as mentioned in the previous chapters. To make clear the relationship between crossability and pollen fertility in view of affinities for each parent, correlation coefficients between those values were calculated, and T-tests were separately made in female and male parents. In view of female and male parents, correlation coefficients between them were -0.1940 and -0.1782, respectively, and showed no significance even at 5 % level, either.

The differences between same characters for two testers were calculated. Correlation coefficients between those values were calculated, and T-tests were separately made in female and male parents. In view of female and male parents, correlation coefficients between them were +0.1039 and -0.0222, respectively, and showed no significance even at 5 % level, either.

ii) *Relation between crossability and seed fertility;* To make clear relationship between crossability and seed fertility, three kinds of calculation were made. Correlation coefficient and linear regression of crossability on seed fertility are shown in Table 12, basing on the strain level and the whole combinations, and T-tests were also made from analyses of variance for two characters. From this table the following facts were ascertained. One strain, No.13, showed a strong positive correlation between them. Correlation coefficient is +0.4880 to the degree of freedom of 28, which is obviously significant at 1 % level. It means that the larger was affinity in crossability, the larger was the seed fertility. Two strains, Nos.11 and 14, showed correlation coefficients as-0.4048 and +0.3624, showing negative and positive correlations between them at 5 % level, respectively. The remaining 13 strains and the whole combinations showed no significance even at 5 % level.

The differences between the maximum and the minimum values of crossability and seed fertility for each parent were calculated as mentioned in the previous chapters.

Table 12. Correlation coefficient and linear regression of seed fertility (Y) on crossability (X). 0 points; 47.5 in both seed fertility and crossability.

Code No.	Correlation coefficient	d.f.	Linear regression
1	0. 2842	28	—
2	0. 3178	28	—
3	0. 0557	28	—
4	-0. 0037	28	—
5	0. 0502	28	—
6	0. 0038	28	—
7	0. 2984	28	—
8	-0. 1194	28	—
9	0. 2437	28	—
10	0. 2104	28	—
11	-0. 4048*	28	Y=--0. 431X+1. 408
12	0. 1198	28	—
13	0. 4880**	28	Y=0. 414X+5. 244
14	0. 3624*	28	Y=0. 693X+4. 198
15	-0. 0237	28	—
16	0. 3549	28	—
Whole	0. 0942	238	—

**, * ; Significant at 1 % and 5 % levels, respectively.

To make clear the relation between crossability and seed fertility in view of affinities for each parent, correlation coefficients between those values were calculated, and T-tests were separately made in female and male parents. In view of female and male parents, correlation coefficients between them were -0.3577 and -0.1639, respectively, showing no significance even at 5 % level. In spite of this, the former value was observed to be nearly significant, that is, in general, the larger was the differences in this respect in crossability, the smaller was the differences in seed fertility.

The differences between the same characters for two testers were calculated. Correlation coefficients between those values were calculated, and T-tests were separately made in female and male parents. In view of female and male parents, correlation coefficients between them were +0.1782 and −0.0621, respectively, showing no significance even at 5 % level.

iii) *Relation between pollen and seed fertilities;* To make clear the relationship between pollen and seed fertilities, three kinds of calculation were made. Correlation coefficient and linear regression of pollen fertility on seed fertility are shown in Table 13, basing on strain level and the whole combinations, and T-tests were also made from analyses of variance for two characters. From this table the following facts were ascertained. Three strains, 3 strains, 2 strains and 8 strains showed significances at 0.1 %, 1 % and 5 % levels and no significance even at 5 % level, respectively. In other words, just half of strains used showed significance and other half showed no significance. In the

Table 13. Correlation coefficient and linear regression of seed fertility (Y) on pollen fertility (X). 0 points ; 47.5 and 67.5 in seed and pollen fertilities, respectively.

Code No.	Correlation coefficient	d.f.	Linear regression
1	0. 3589	28	—
2	0. 3077	28	—
3	0. 6975***	28	Y=1. 139X−0. 069
4	0. 3109	28	—
5	0. 4810**	28	Y=0. 711X+0. 025
6	0. 2217	28	—
7	0. 3414	28	—
8	0. 2712	28	—
9	0. 5614**	28	Y=0. 996X+0. 143
10	0. 7093***	28	Y=1. 120X+0. 157
11	0. 4449**	28	Y=0. 643X+1. 800
12	-0. 2078	28	—
13	0. 2551	28	—
14	0. 3999*	28	Y=0. 505X−0. 176
15	0. 3942*	28	Y=0. 574X−0. 418
16	0. 6578***	28	Y=1. 111X−0. 377
Whole	0. 6468***	238	Y=1. 390X−1. 327

***, **, * ; Significant at 0. 1 %, 1 % and 5 % levels, respectively.

whole strains, the value was of high significance at 0.1 % level. Pollen fertilities of all combinations are shown in Table 14 in relation to the seed fertility. There is apparently a strong positive correlation between them. Correlation coefficient is +0.6468 to the degree of freedom of 238, which is obviously significant at 0.1 % level. Generally speaking, the higher is the pollen fertility, the higher is the seed fertility. This finding was clearly different from the relations between crossability and pollen fertility, and crossability and seed fertility.

Table 14. Pollen fertility of all the F_1 hybrids in relation to their seed fertility. Figure used in the table shows the number of combinations.

Seed fertility (%)	Pollen fertility (%)													Total
	100~96	95~91	90~86	85~81	80~76	75~71	70~66	65~61	60~56	55~51	50~46	45~41	40~36	
95~91		1	3											4
90~86	1	8	4	2										15
85~81		5	1	3	4	1	1	1						16
80~76	2	6	7	2				1		1				19
75~71	2	8	6	7	2	1	1	1	1					29
70~66	2	8	1	6	5		2				1	1		26
65~61	2	9	3	3	1	5		1		1				25
60~56	2	5	2	2	1	1	1							14
55~51	1	2	6	1		1		1	2	1	2			17
50~46		3	3	2	1		2				1			12
45~41			2	3	1	2	2	2				1		13
40~36		2	3	2	2	1	3		1					14
35~31		2					1	1			1		1	6
30~26				1	1				1	1		1		5
25~21		1		1				1		2	1	2		8
20~16			2	1					2	1				6
15~11						3				1		1		5
10~ 6							1			1	1			3
5~ 1		1		1	1									3
Total	12	61	43	37	19	15	14	9	7	9	7	6	1	240

$r=+0.6468$*** (d.f.=238), significant at the 0.1 % level.

The differences between the maximum and the minimum values of pollen and seed fertilities for each parent were calculated as mentioned in the previous chapters. To make clear the relation between pollen and seed fertilities in view of affinities for each parent, correlation coefficients between those values were calculated, and T-tests were separately made in female and male parents. In view of female and male parents, correlation coefficients between them were +0.2766 and +0.3291, respectively, and showed no significance even at 5 % level.

The differences between same characters for two testers were calculated. Correlation coefficients between those values were calculated, and T-tests were separately made in female and male parents. In view of female and male parents, correlation coefficients between them were +0.0437 and +0.4280, respectively, and showed no significance even at 5 % level. Although no significance was to be observable, the latter value was fixed to be of slight significance, that is, in general, the larger was the difference in this respect in pollen fertility, the larger was the difference in seed fertility in the present sense.

DISCUSSION

1) As the pioneer work, KATO *et al.* (1930)[11] proposed to divide *O. sativa* into two sub-species, *japonica* and *indica*, on the basis of morphological differences, serological reaction and sexual affinity, using about 200 strains. The finding of hybrid sterility between the two groups aroused much interest among rice workers. Later studies with large collections showed that the morphological variations between the two variety-groups were not discontinuous and the phenomenon of intervarietal hybrid sterility was too complicated to allow them to be classified into two distinct groups (OKA[20], TERAO *et al.*[26]). The inclusion of a number of *bulu* from Java (WAGENAAR *et al.*[29]) indicated that they formed a morphologically distinct group (MATSUO[16]). The *javanica* varieties showed a very high affinity with Japanese varieties and a high to very high affinity with most of the *indica* varieties (TERAO *et al.*[27]). Thus, three major variety-groups are generally recognized by many workers. However, these idea of dividing rice varieties into geographical races is rapidly losing its significance in accordance with further intensive works (CHANG[1]). Moreover, hybridization by breeders has further confused the classification schemes. Despite the short-comings the term *indica* and *japonica* are often used as some convenient terms to designate different plant and grain types (CHANG[1]).

Extensive hybridizations with rice varieties have been made by many workers[4,5,6,19]. GHOSH *et al.*[4] stated that the *aman* type is significantly different from *aus*, *japonica* and *javanica* in respecting to the variances for any of the dimensions. At a glance, the *japonica* and *aus* types also differ significantly from each other. But this turns out untrue, when these two variances are brought under minute comparisons. In *aman* and *javanica* types the volumes of the embryo and the endosperm are significantly and positively correlated, but in case of *aus* and *japonica* types such a correlation as this is unsignificant. The present findings confirm the view that *aman* and *japonica* types constitute distinct sub-groups amongst cultivated rices. The *aus* types are a heterogeneous assemblage which have evolved as ecotypes from the *aman* rice. As the *javanica* types consisting of sub-types *bulu*, *tjereh* and *gundil* have been treated as a single unit, no definite conclusions were to be obtained in regard to their affinities with other groups. Neverthless the *javanica* group shows similarity to both *aus* and *aman* types concerning the grain- and embryo-sizes.

2) A number of hypotheses regarding the putative indigenous centres of *O. sativa* have already been published, and CHANG[1] having summarized these hypotheses. Archaeological evidence found in India dates the antiquity of rice to 1,000 B. C. (CHATTERJEE, 1951[2]). Probably rice-cultivation was brought forth about ten thousand years ago.

The generally accepted origin of *O. sativa* is fixed to be in the area embracing south

Asia, southeast Asia and China (ROSCHEVICZ, 1931[22] and others). CHOU[3] and others held that China is one of the primary centres of the origin and that the differentiation of the *japonica* varieties took place in China. MORINAGA[17], basing on the broader works using many Himalayan varieties, stated that Himalaya is indigenous centre of Asiatic cultivated rice. KIHARA *et al.*[12] and KATAYAMA[7,8,9] held that Sikkim might be one of the differentiation centres of *O. sativa* into *japonica* and *indica*, judging from the diallel crosses using several strains collected in Sikkim and other countries. RAMIAH *et al.*[21] stated that cultivated rice had been originated in south India, and *japonica* type must have been developed later from *indica* type. KATAYAMA[10] indicated also, basing on embryo transplantation that *indica* type might have occurred first from the putative ancestor and afterward, *japonica* type might have been derived from *indica* type.

3) Diallel analyses have been employed for many respects, during the past ten years[14,15,18,25,28,30]. THEURER *et al.*[28] and WHITE *et al.*[30] researched for super germ plasm of cotton, and selection of alfalfa, respectively. MARANI *et al.*[15] and NIEHAUS *et al.*[18] studied about heterosis and combining ability of tobacco and sorghum, respectively. Diallel analysis can also be employed for determining the cytoplasmic inheritance.

4) KIHARA *et al.*[13] reported *indica* and *japonica* types in Sikkim rice based on the examination of morphological characters, phenol reaction and seed fertility. The most important key for the classification of cultivated rice into *indica* and *japonica* types is the hybrid sterility between strains. Therefore, in order to confirm the classification of Sikkimese varieties, pollen fertility of F_1 hybrids with *indica* and *japonica* test-strains was studied (KIHARA *et al.*[12]). Considering the data obtained in this report, it is assumed that the differentiation of *indica* and *japonica* types in cultivated *O. sativa* might have occurred in the Indian sub-continent, particularly in Sikkim. Furthermore to clarify the relationships between its strains, diallel crosses were carried out using sixteen strains, namely, fourteen Sikkimese rice, one type of *indica* strain and another type of *japonica* strains[7,8,9]. Basing on the data obtained in three reports mentioned above, Sikkimese rice is fixed to be composed of typical *japonica*, typical *indica* and *intermediate* types. Then the following conclusion was again drawn that Sikkim might be one of the differentiation centres of cultivated rice into *japonica* and *indica* types. However, as the analysis and conclusion have left several items in question, further analysis was made here in detail.

5) Basing on the results obtained in this experiment, several problems will be discussed here.

i) ***Pure line;*** Pure line strains used here have showed normal values in artificial pollination-ability. This finding was made sure by the following experiment. In pollen fertility, one strain, No.15 (Champasari) showed relatively low value, although most strains showed normal values. In seed fertility, several strains showed relatively low values. One of them, No.7 (Tokmor Zo), is said to be a relatively primitive type of cultivated rice. And other varieties, Nos.13 and 14 (Fudangay), are said to be growing in high altitude[13]. It may be said that some of the rice varieties cultivated in Sikkim were genetically considerable heterozygous and have been differentiating down to this day.

ii) ***Crossability;*** Crossabilities in No.3 × No.15 and No.15 × No.3, reciprocals, were very low. As shown in Tables 2 and 3, No.3 (Addey) and No.15 (Champasari) showed low crossabilities for all partners. Such strain has been said to have always genically low crossability. On the other hand, there is some advantageous strain, whose crossability being very high for a lot of partners. Low crossability may be noted in two meanings; the one is to interpolate it as the specific character of the strain which is due to gene action and the other is to regard it as the behaviour of opening the fertile glumes. The former was supported by the following fact that crossing with No.11 × No.4 was very difficult but No.4 × No.11 (reciprocal relation with each other) was very easy, even when both of which were carried out in the same day. The latter was supported by the following fact that some strain opened immediately its lemma and palea during the emasculation in hot water (No.15). Such floret was wetted by hot water during the emasculation and then this opening behaviour may be placed disadvantageously for the following pollination. Reciprocal differences were not recognized, clearly, excepting for No.3, but considerable differences were recognized in several strains. In such strains, one of the two reasons mentioned above may be more or less fitted for explaining the phenomenon.

The differences between the maximum and the minimum values of crossability for each strain showed very large range, giving notice of more extensive differentiation in rice varieties more than that in case of the so-called *indica* and *japonica* varieties. This interpretation was supported more clearly in the differences, in which Sikkimese rice varieties were crossed and compared with two testers. The differences of crossability for the testers in the average were −7.71 and −5.86 in the female and male parents, respectively, when the crossability for *indica* type was set as the larger side.

The crossability was placed more disadvantageously for testing the character of variety differentiation than pollen and seed fertilities were, because the crossability was partially controlled by some environmental conditions in many cases. Then, the latter two were considered to be biologically more secure and significant than the former one.

iii) *Pollen fertility;* No.2 (*japonica*) showed the minimum pollen fertility in strain level, showing fertility lying near the maximum (Table 3), at the time when it was used as female and male parents, respectively, although none was significant in reciprocals (Table 6). It may be said that this strain has been extremely differentiated during the long history of variety differentiation, in which the ancestral strain has been extended for Japan. On the other hand, some strains *i.e.*, Nos.12 (Tapachini), 7 (Tokmor Zo) or 4 (Lama), showed high affinities for most strains, at the time when it was used both as female or male parents. This discrepancy found may be due to the differences of the respective history.

Pollen fertilities for individual plant level ranged from 28 to 99 percent. MORINAGA[17] stated that pollen fertilities ranged from 5 to 94 percent using Himalayan and Japanese strains. JENNINGS[5] stated that pollen fertilities ranged from 2 to 100 percent using many varieties. The figure in the data obtained here was clearly higher in the lowest value than that of the two previous authors mentioned above. The differences found here may be due to the difference of the varieties used.

The differences between the maximum and the minimum values of pollen fertility for each strain showed very large, and gave notice also of extensive differentiation in rice varieties more than those of the so-called *indica* and *japonica*, the same as in case of crossability. This phenomenon was more clearly ascertained in the differences, in which Sikkimese rice varieties were crossed and compared with two testers. The differences of pollen fertility for two testers in the average were −7.29 and +15.07 in the female and male parents, respectively, at the time when the pollen fertility for *indica* type was fixed as the one on the larger side.

In reciprocals, the data obtained did not suggested special cytoplasmic influence on the pollen fertility.

iv) *Seed fertility;* In view of reciprocal relation, seed fertilities were very low in the combinations, No.2 × No.11, No.2 × No.16, No.7 × No.15, No.14 × No.16 and in its reciprocals. On the other hand, seed fertilities were very high in No.15 × No.16 and its reciprocal. These phenomena were not found in crossability and pollen fertility, and therefore fixed as a specific character in seed fertility. The differences between the maximum and the minimum values of seed fertility for each strain showed very large, and gave notice also of more differentiation than that of the so-called *indica* and *japonica*, the same as in case of crossability and pollen fertility. This phenomenon was ascertained in the differences, in which Sikkimese rice varieties were crossed and compared with two testers. The differences of seed fertility for two testers in the average were +18.36 and −4.86 in female and male parents, respectively, at the time when the seed fertility for *indica* type was fixed as the one on the larger side.

As mentioned by JENNINGS[5] and others, the existence of pollen fertility which is higher than seed fertility in most hybrids has been a matter of question. Against this issue three assumptions have been made hitherto. Unfavorable environmental conditions, particularly lodging, shattering, changes of temperature, which were exceedingly lodging and shattering, or relative humidity were assumed to be the causes of the reduction of seed-fertility. The first assumed cause was avoided by the procedure, in which weak-strawed hybrids and parental plants were individually supported with stakes. It may reasonably happen that on account of insufficient pollination no seed-setting is to be brought on to some potentially fertile ovules. As pointed out by SAMPATH[23], the undersized and highly stained pollen grains were rated as fertile and large variation in seed fertility occurred with crosses. As shown in Table 5, variation of pollen-grain-size was certainly found. In 59 from the whole 240 combinations (=24.58 %), the large and the small pollen grains were mixed, together. This phenomenon was not necessarily found in reciprocal combination. It doesn't necessarily follow that the strain having mixed pollen in its size shows low seed fertility (cf. Tables 5 and 8). No further consideration was not intended here, as no accurate counting of each size and count of percentage were made here. The pollen fertility which was higher in comparison with seed-fertility may perhaps be maximized by either or both of these facts mentioned above.

v) *Standard deviation of each character;* In general, it was said from the data shown in Table 3, that the higher was the average value, the lower was the standard deviation in three characters. However, it should be noted whether the absolute value of the average was relatively high or low. In an extreme case, the average and standard deviation in crossability were 9.20 and 5.19, respectively, at the time when No.16 was used as female parent. It was sufficiently considered that the latter value was small owing to the fairly low value of the former one. Furthermore, it was recommended that standard deviation in only one character was not to be considered, separately, and that those of many characters were to be compared at the same time. It was of interest that the standard deviation was relatively small in one character but large in another character. For example, the standard deviations were small in crossability but large in pollen fertility, at the time when Nos.14 and 16 were used as female and male parents in view of strain average. On the other hand, the deviations were large in crossability but small in pollen fertility, at the time when Nos.4, 6, 7 and 12 were used as female and male parents. Lastly, it was left as a future matter in question that the difference of affinity is to be revised by some method. To make clear the difference, for example, the affinity should be taken off from the value of one or both parents.

vi) *Relation of each character;* As shown in Tables 11, 12 and 13, correlations between each character were differing from each other. Although some significant correlations were ascertained on strain level in relation between crossability and pollen fertility, between crossability and seed fertility, significant correlation was found only in relation between pollen and seed fertilities on the whole combinations. It may be noticed that the pollen and seed fertilities found were more stabilized than crossability and were looked upon as always the strain or combination specificity.

vii) *Grouping;* SHARMA *et al.* (1971)[24] proposed a project for the systematic collection of the current and primitive cultivars of rice from the north-east part of India. So, several types of gene pool in cultivars from Sikkim, showing the variety differentiation in large scale, may reasonably be expected. Then, the grouping of the 16 strains used were thrice attempted basing on the data obtained on crossability, pollen and seed fertilities. At first, as shown in the previous paper[8], the grouping was made only in reference to pollen fertility, and 16 strains were divided into two groups. Eleven strains, *i.e.*, Nos.1, 4, 5, 6, 9, 10, 11, 12, 13, 15 and 16, were regarded as *indica* group, and 5 strains, *i.e.*, Nos.2, 3, 7, 8 and 14, were regarded as *japonica* group, respectively. Average pollen fertilities and the standard deviations of these were 89.8±16.2, 72.0±19.7, 68.3±19.3 and 85.5±13.7 in *indica* (♀) × *indica* (♂) (110 combinations), *indica* × *japonica* (55 combinations), *japonica* × *indica* (55 combinations) and *japonica* × *japonica* (20 combinations), respectively. However, as mentioned in the previous chapters, some strains showed always relatively high or low affinities for common varieties.

So, re-classification would be kept in mind, three strains *i.e.*, Nos.9, 10 and 13, were found to be of *intermediate* type between *indica* and *japonica* types[9]. Eight strains, *i.e.*, Nos.1, 4, 5, 6, 11, 12, 15 and 16, at least 3 strains, *i.e.*, Nos.9, 10 and 13, 5 strains, *i.e.*, Nos.2, 3, 7, 8 and 14, were classified here as *indica*, *intermediate* and *japonica* groups, respectively. Basing on the calculation, crossabilities and these standard deviations, the average values found in each group were shown as 32.24±23.62, 24.38±18.67, 25.96±21.36, 26.64±16.68, 27.86±16.95, 23.44±10.27, 32.12±18.84, 30.51±20.70 and 23.41±12.69 in the groups of *indica* (♀) × *indica* (♂) (56 combinations), *indica* × *intermediate* (24 combinations), *indica* × *japonica* (40 combinations), *intermediate* × *indica* (24 combinations), *intermediate* × *intermediate* (6 combinations), *intermediate* × *japonica* (15 combinations), *japonica* × *indica* (40 combinations), *japonica* × *intermediate* (15 combinations) and *japonica* × *japonica* (20 combinations), respectively. Pollen fertilities and the standard deviations of these were shown as 82.15±12.16, 83.35±8.69, 82.75±4.26, 79.06±13.60, 89.33±4.23, 80.44±10.01, 78.89±15.98, 74.52±19.58 and 75.64±19.05 in the same order, respectively. Seed fertilities and the standard deviations of these were shown as 62.85±15.48, 69.00±18.17, 57.55±23.80, 62.99±20.92, 71.12±12.50, 50.59±27.22, 54.20

±20.51, 55.75±18.73 and 45.10±22.01 in the same order, respectively. In the data mentioned above, the following facts were ascertained that intra-fertile groups were recognized only in four cases in view of the absolute values, *i.e.*, crossability in *indica*, crossability, pollon and seed fertilities in *intermediate*. In these four cases, the absolute values were superiorly larger than that of the inter-semi-sterile groups. In view of the standard deviation, 4 cases, *i.e.*, seed fertility in *indica*, pollen and seed fertilities in *intermediate*, crossability in *japonica*, showed clearly intra-fertile groups, in which the values of standard deviation were superiorly smaller than that of the inter-semi-sterile groups. So, this classification may be regarded as useful, but has not been ascertained enough to be recommended.

The third grouping was made, using the following about 40 characters, *i.e.*, absolute values, the standard deviations, differences between the maximum and the minimum values for each strain, at the time when the respective strain were crossed for all strains and for two testers, in regard to three characters, *i.e.*, crossability, pollen and seed fertilities, and these correlation between several characters. In this case, 8 strains, *i.e.*, Nos.1, 3, 4, 5, 8, 13, 14 and 15, 4 strains, *i.e.*, Nos.9, 10, 11 and 16, and the other 4 strains, *i.e.*, Nos.2, 6, 7 and 12, were tentatively classified here as *indica*, *intermediate* and *japonica* groups, respectively. Then, three intra-fertile and six inter-partial-sterile groups were proposed here. Average values and standard deviations found in crossability, pollen and seed fertilities found in each group were shown in Table 15. From these data, the following facts were ascertained that intra-fertile and inter-semi-sterile groups were considerably recognized. Then, this classification would be more recommendable than that of the former two classifications. However, one intra-fertile group of them, *i.e.*, *indica* × *indica* (56 combinations), showed relatively low significance and were expected to be more differentiated than other two intra-fertile groups.

In view of varietal and geographical points, several issues could be drawn, basing on the data shown in Table 15. In regard to this tentative classification, varieties belonging to Lama, Fudangay and Champasari were classified as *indica* group, and varieties belonging to Tokmor Zo and Tapachini were classified as *japonica* group. On the other hand, varieties belonging to Addey were segregating to *indica* and *intermediate* types. Kihara *et al.*[13] stated that Addey is the most important and popular rice in the mid-altitude of Sikkim and belongs to *Aman* group. So, segregation of Addey variety found here was explained to have had long history, evolving through environmental reasons and human selection into several types having many economic traits of primary interest to rice breeders. As mentioned in the third grouping scheme, varieties belonging to *indica* were more abundant than *japonica*. This finding was fitted for the previous report[13], in which it was said that most of rice varieties in Sikkim belong to *indica* and nearly one tenth of which belong to *japonica*. Other varietal relations were not clearly explained, so far as the analysis was made only using the data obtained in this experiment.

viii) *Generality;* Through all the combinations made and these characters measured, it was concluded that reciprocal differences did not suggested considerable cytoplasmic influence. However, there remained several clearly unexplainable matters in question. For example, two strains showed mutually extreme repulsion on the affinity, but both of them showed, on the other hand, intimate reaction on the affinity for another strain. Some environmental factors are also expected as another questionable issue on revela-

Table 15. Tentative grouping of strains used and values of three characters found in intra-fertile and inter-semi-sterile groups; illustrating the average values and the standard deviations of these. Three figures in each quardrangle, from top to bottom, indicate the crossability, pollen fertility and seed fertility, respectively.

♀ \ ♂	*indica* (8 strains)	*intermediate* (4 strains)	*japonica* (4 strains)
indica (8 strains)	25.35±18.28 77.16±17.93 56.59±20.04	30.56±14.94 76.53±14.30 58.57±16.68	33.47±23.69 87.80± 9.45 58.93±24.06
intermediate (4 strains)	16.29±15.00 75.19±13.48 53.96±21.92	17.92± 9.66 90.76± 3.19 83.66± 7.39	17.28± 8.32 81.11± 8.98 49.83±24.90
japonica (4 strains)	37.68±21.34 82.21±15.46 62.39±20.86	41.78±19.25 73.60±15.88 57.06±21.29	36.44±20.14 87.13± 9.46 59.61±12.76

indica : No.1, No.3, No.4, No.5, No.8, No.13, No.14 and No.15.
intermediate : No.9, No.10, No.11 and No.16.
japonica : No.2, No.6, No.7 and No.12.
□ and others: intra-fertile group and inter-semi-sterile group, respectively.

tion of the affinity, because some affinity was considerably changeable year by year. The fact that definite grouping can not be gotten would be due to these phenomena and others. The ultimate significance of partial sterility may not be ascertained without the aid of the experiment using F_2 or the following progenies.

In conclusive consideration on the varietal and geographical relationships, the following four ideas were noted basing on the data obtained here; 1) diallel cross may be in possession of the meaning enough to explain the relationship between several varieties; 2) the differentiation of rice varieties might have occurred in the Indian sub-continent, particularly in Sikkim or its adjacent regions; 3) varietal differentiation may have been extensively and continuously occurred in large scale over the differentiation for the so-called *indica*, *japonica* or *javanica* types; 4) and at last, as mentioned by CHANG[1], any scheme of dividing rice varieties into geographical races has been losing its significance rapidly, in other words, the more extensive is the experiment, the more confused is the classification of rice varieties.

SUMMARY

In order to confirm the classification of rice varieties, *Oryza sativa* L., and to clarify the relationships between them, 14 strains of Sikkimese rice varieties and one type of *indica* and another type of *japonica* were picked up, and diallel crosses were carried out, constituting 240 combinations. In this report, crossability, pollen and seed fertilities and relationships of these were mainly described. Extensive considerations on classification and the occurred varietal differentiation were discussed. The main points obtained during this study were summarized as follows:

1) *Crossability;* Self pollination-ability by artificial procedure showed in ranging from 90.3 % to 99.2 %, showing 94.2±4.4 in average of the whole 16 parental strains. All the crosses (=240 combinations) were successful. Crossabilities making hybrid were widely ranging from 1 % to 97 % in plant level and from 1 % to 93 % in combination level. The average and its standard deviations were shown as 28.4±17.0. The differences of crossability in the parental and combination levels were ascertained as very large in accordance with each parent. In view of reciprocal combination, only 1 strain showed negative significance, and none was significant in the whole strains. The differences between the maximum and the minimum values of crossability for each parent in view of the female parent ranged from 17.4 % to 77.5 %, showing 52.1±15.8 in average. Those in view of male parent ranged from 42.0 % to 88.9 %, showing 61.2±13.4 in average. Correlation coefficient between them was +0.510 and showed significant at 5 % level. Differences of crossability of Sikkimese rice for two testers in view of female parent ranged from 2.3 % to 80.4 %, showing 16.3±19.1 in average. Those in view of male parent ranged from 0.2 % to 48.3 %, showing 20.3±15.4 in average. Correlation coefficient between them was +0.093, showing no significance.

2) *Pollen fertility;* Pollen fertilities of parental plant ranged from 67.2 % to 98.6 %, showing 92.1±7.7 in average. Pollen fertilities of F_1 hybrid ranged from 28 % to 99 % in plant level and from 40 % to 98 % in combination level, showing 80.1±16.4 in average. The differences of pollen fertility in the parental and combination levels were ascertained to be very large in accordance with each parent. In view of reciprocal combination, about half of strains and the whole combinations showed positive significance. Then, it was concluded that reciprocal differences did not suggested considerable cytoplasmic influence on the pollen fertility. The differences between the maximum and the minimum values of pollen fertilities for each parent in view of the female parent ranged from 19.9 % to 54.9 %, showing 42.3±10.3 in average. Those in view of male parent ranged from 22.0 % to 53.3 %, showing 43.0±8.1 in average. Correlation coefficient between them was +0.448, showing no significance. Differences of pollen fertility of Sikkimese rice for two testers in view of female parent ranged from 0.3 % to 37.4 %, showing 11.3±9.7 in average. Those in view of male parent ranged from 3.0 % to 35.6 %, showing 17.2±10.3 in average. Correlation coefficient between them was −0.293, showing no significance.

3) *Seed fertility;* Seed fertilities of parental plant ranged from 26.0 % to 95.3 %, showing 75.3±15.8 in average. Seed fertilities of F_1 hybrid ranged from 1 % to 97 % in plant level and from 1.5 % to 95.4 % in combination level, showing 58.7±21.3 in average. The differences of seed fertility in the parental and combination levels were ascertained

to be very large in accordance with each parent. In view of reciprocal combinations, about three fourth strains and the whole combinations showed positive significance. Then, it was concluded that reciprocal differences did not suggested considerable cytoplasmic influence on the seed fertility. The differences between the maximum and the minimum values of seed fertilities for each parent in view of the female parent ranged from 42.4 % to 85.4 %, showing 67.0±13.8 in average. Those in view of male parent ranged from 38.5 % to 85.6 %, showing 63.9±12.9 in average. Correlation coefficient between them was +0.443, showing no significance. Differences of seed fertility of Sikkimese rice for two testers in view of female parent ranged from 1.1 % to 55.4 %, showing 26.5±15.9 in average. Those in view of male parent ranged from 1.7 % to 43.8 %, showing 18.8±12.7 in average. Correlation coefficient between them was +0.437, showing no significance, either.

4) *Relation between three characters;* Correlation coefficients between crossability and pollen fertility showed negative significances in two strains. Those in 14 strains and the whole showed no significance. Correlation coefficients between crossability and seed fertility showed negative and positive significances in one and two strains, respectively. Those in 13 strains and the whole showed no significance. Correlation coefficients between pollen and seed fertilities showed positive significances in 8 strains and the whole, but those in the remaining 8 strains showed no significance.

5) *Grouping;* There were many peculiar strains in view of affinity on the crossability, pollen and seed fertilities. Some one showed high affinities for each strain, another showed the reverse behaviour, while, another showed high value only for a few strains. Moreover, variations of pollen-grain-size were found in wide range. So, clear cut classification of rice varieties is not to be proposed at present. However, groupings were tentatively made here, thrice. In the most recommendable classification, the grouping was done basing on about 40 characters of crossability, pollen and seed fertilities. Seven, 4 and 3 strains of Sikkimese varieties were divided as *indica*, *intermediate* and *japonica* types, respectively, basing on the data of intra-fertile and inter-semi-sterile groups.

6) *Generality;* The following four conclusions on the varietal and geographical relationships may be drawn; diallel cross may be in possession of a noteworthy meaning for these experiments; varietal differentiation might have been continuously occurred in large scale over that of the so-called *indica* and *japonica*; differentiation might have been occurred in the Indian sub-continent, particularly in Sikkim; and any scheme of dividing rice varieties into geographical races may be rapidly losing its significance year by year.

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