FURTHER REPORT ON MUTATION BREEDING OF RICE IN TAIWAN SINCE 1957[1]

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In the early days, breeding by induced mutation of rice by irradiation was seldom attempted in Taiwan simply because that the frequency of favorable mutations obtained was too low to encourage any attempt for a trial. Owing to the growth of population in Taiwan, the conventional method of breeding seems to be rather limited in its effectiveness to cope with this population pressure so that any other possible method of breeding should be studied. The success of using radiation to induce favorable mutations in barley (Gustafsson, 1953; 1960) and peanuts (Gregory, 1955; 1957) opened up a new path in the methodology of plant breeding. In 1955, the Agricultural Research Institute of Taiwan and the Taichung District Agricultural Improvement Station started several projects of induced mutation of rice under the sponsorship of the Sino-American Joint Commission for Rural Reconstruction. However, up to the present no commercial variety ever came out from induced mutation breeding by that station. In 1957, we also started a cooperative project on rice improvement by irradiation. In the first year, ten varieties were treated with different doses of X-rays in the Union Industral Institute of Taiwan (Hsinchu) and a number of promising lines were found after the treatment (Hu *et al.*, 1962; Li *et. al.*, 1962). The following year, a batch of seeds was treated with X-rays at the University Hospital of National Taiwan University in order to study the proper dosage of radiation for the practice of radiation-breeding in rice (Kao *et al.*, 1960). In 1959, seeds of Taichung 65 (ponlai variety, *Japonica*) were sent to Brookhaven National Laboratories, U. S. A., to be treated with X-rays and gamma rays aiming to produce resistant mutant lines to rice blast disease. Again in 1960, batch of four varieties, two ponlai and two native

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(*indica*) varieties were sent to the same Laboratories to be irradiated with dosages of X-ray and thermal neutrons. These four varieties are generally considered to be high-yielding as well as resistant to rice blast disease. The common weakness of these varieties nevertheless is that they are rather weak in growth and are therefore susceptible to severe lodging after heading.

The aim of this project is: 1), to obtain erectoid type of plants which is stiff-strawed and is responsive to nitrogenous fertilizer; 2), to obtain early-maturing strains which would yield the same or more than their original variety so that the multiple cropping system of Taiwan can be easily handled; and 3) to obtain disease resistance strain. The ponlai varieties should be resistant to *Piricularia oryzae* and the natives to *Xanthonomas oryzae* and *Corticum sasakii*. This paper tries to bring the results up to date since 1957.

Materials and Methods

Rice varieties and irradiation dosage used in the experiments are given in table 1. The exact dosages of thermal neutrons however could not be estimated, but were considered to be similar to the dosage of X-rays of 15, 20 and 25 kr. Most of the breeding work were done at the experimental field of Chung-Hsing University at Taichung. Panicle selection was practised at X_1 generation. The selected X_1 panicles were planted in X_2 generation in head-rows. In the X_3 generation, selections were made of lines which showed no further segregation and for comparison, the original varieties were interplanted to be used as checks. In X_4 generation selections were based on the performance of the individual strains. Only those which out-yielded the originals or strains were selected. Selected strains showing no further segregations were tested in the primary yield trials each with one replication. Those which were selected

Table 1. *Varieties used and their treatments of irradiations*

Varieties	Dosages of X-ray (kr)		Dosages of Thermal neutron (hours)	Treated year	Sub-species
	Dormant seeds	Water-soaked	Dormant seeds		
Taichung 65	20, 25, 30	5.5		1957	*Japonica*
Ming-tong*	15, 20, 25, 30			1957	*Indica*
Ching-kuo-chang*	15, 20, 25, 30			1957	*Indica*
Shuang-chiang*	15, 20, 25, 30			1957	*Indica*
Keh-tze*	15, 20, 25, 30			1957	*Indica*
Chianung 242	15, 20, 25		3, 4, 5,	1960	*Japonica*
Taichung 179	15, 20, 25		3, 4, 5,	1960	*Japanica*
I-kung-bau	15, 20, 25		3, 4, 5,	1960	*Indica*
Wu-ko-chin-yu	15, 20, 25		3, 4, 5,	1960	*Indica*

* Second crop variety

from the primary yield trials were further tested in the fertilizer response test. A "3×3 Latin Square Split Plots design was used for the testing. The levels of fertilizers applied are listed in table 2.

Table 2. *Levels of fertilizer application in the fertilizer response tests*

Sub-species	Levels	N (kg/ha.)	P (kg/ha.)	k (kg/ha.)
Japonica mutants	0 1 2	0 80 160	0 40 80	0 40 80
Indica mutants	0 1 2	0 40 80	0 20 40	0 20 40

Experimental Results

1. Fertilizer-response test and regional test of mutant lines obtained from native varieties.

The four native varieties, Ming-tong, Ching-kuo-chang, Shuang-chiang and Keh-tze were treated with X-rays in 1957. Since these varieties were short-day plants, they could only be grown in the second crop season (July-November). To the X_5 generation, a total of sixteen mutant lines were selected from the above four varieties. From X_6 to X_8 (1962–1964) these lines and their original varieties were tested for fertilizer response. The amount of fertilizer application listed in table 2. The results of this experiment indicated that the erectoid strains derived from these non-erectoid varieties could stand upright even when the field was heavily fertilized. The comparison of the yields of the mutants to their original varieties (CK) is shown in table 3. The yield of the mutant lines was generally more or less similar to their original varieties. It is noteworthy to note that the erectoid lines descended from the short-day varieties lost their photosensitivity. Thus they could be grown in the first crop season (February-Iuly) when long-day photoperiod prevailed. It would be of particular interest to point out that one of the mutant lines derived from Shuang-chiang (Sh 30–21) responded well with the application of fertilizer (table 3); it can be seen that the heavier the dosage of fertilizer applied the higher was the yield and the difference was found to be significant statistically. The functional ability of this mutant was somewhat similar to the erectoid mutants which Gustafsson obtained in barley. Some of barley mutant could respond excellently to heavy dressing of nitrogenous-fertilizer. The erectoid mutants of I-kung-bau and their original strains are shown in Fig. 1.

In order to test the adaptative and yielding abilities of the mutants at different localities, twelve strains were selected to be tested in the regional test which was held at three different places in and around Taichung. Results of this

Table 3. *Yield comparison of mutants from native second crop varieties on fertilizer response test.* (*1962–64, second crop*)

Mutant lines	Levels of fertilizer		
	0	1	2
Ming-tong (CK)	100.0% (3,594.3kg/ha.)	100.0% (3,927.7)	100.0% (3,672.1)
MT 25-29	104.6	95.5	102.4
MT 30-32	102.0	96.5	100.4
Ching-kuo-chang (CK)	100.0% (3,094.4kg/ha.)	100.0% (3,083.3)	100.0% (3,080.5)
CKC 15-36	122.0	120.8	128.5
CKC 30-33	121.0	137.6	121.1
Shuang-chiang (CK)	100.0% (2,999.9kg/ha.)	100.0% (3,144.4)	100.0% (2,724.9)
Sh 20-62	109.4	100.4	110.0
Sh 30-21*	103.0	109.3	115.9
Keh-tze (CK)	100.0% (3,936.0kg/ha.)	100.0% (4,035.2)	100.0% (3,988.8)
KT 15-11	106.7	111.6	108.4
KT 15-65	100.7	107.9	108.0
KT 20-42	98.2	101.2	98.8
KT 20-67	110.3	109.4	110.1
KT 20-73	107.5	103.0	102.9
KT 20-74*	87.4	89.5	86.6
KT 25-31	104.3	104.9	103.2
KT 25-56	98.8	105.9	102.2
KT 30-26	98.1	95.0	102.7
KT 30-28	91.2	96.4	92.0

* erectoid

regional test are given in table 4. From this table it can be seen that the yield averages of the two erectoid mutant lines, Sh 30-21 and KT 20-74 were a little higher than that of the erectoid variety Taichung native 1 which was used as the check. This latter variety is very high yielding now extensively cultivated in Taiwan. The other two erectoid mutant lines of IKB 4-1 and 4-2 were derived from I-kung-bau by the thermal neutron treatment. I-kung-bau is grown originally in the first crop. They seemed to be of good promised in the second crop also. The yield of the hybrid line obtained from the cross Taichung native 1 × Sh 30-21 was the highest of all (significant at 5% level). It seems that breeding hybridization with the induced mutants may be of good promise in the future.

2. Hybridizations of two induced mutants derived from Taichung 65.

The erectoid mutants derived from the ponlai variety Taichung 65 (*japonica*) were lodging resistant even if the field was heavily fertilized. However, their

Table 4. *Comparison of the mutants from second crop varieties at three localities (1964 second crop)*

Mutant lines	Chung Hsing University (Taichung)	Er-lin	Luc-kon	Average
Taichung native 1 (CK)	100.0% (5,590.0kg/ha.)	100.0% (7,124.0)	100.0% (6,940.0)	100.0% (6,551.3)
KT 15-11	106.0	95.7	83.9	95.2
KT 15-65	90.5	103.7	84.7	93.0
KT 20-67	106.4	102.6	89.3	99.4
KT 20-74*	117.4	101.1	90.8	103.0
KT original	96.7	101.1	80.3	92.7
CKC 30-33	81.6	58.9	55.1	65.2
CKC original	70.5	57.4	28.8	52.2
IKB 4-1*	110.0	101.0	94.7	101.9
IKB 4-2*	107.7	103.7	103.0	104.8
I-kung-bau	100.2	101.1	70.4	90.6
Sh 30-21*	109.2	101.6	89.9	100.2
TN 1×Sh 30-21−44-5	113.8	103.1	106.3	107.6

* erectoid

panicles were smaller than that of the original variety and did not show any increase in yield over the original variety after they were tried out in the fertilizer-response experiments. On the other hand, the head type of the large panicle mutants (over 150 grains per panicle) gave a slightly better yield than the original variety under heavy fertilization but they were susceptible to lodging. A combination of these two good mutant types, erectoid mutant and large panicle mutants, by hybridization for the purpose of creating an erectoid type with a large panicle was made in the first cropping season of 1959. Finally eight lines were selected in the F_4 generation in the first crop of 1961. During the second crop of the same year, a Latin Square Split Plot design was used to test the fertilizer response of these selected strains together with their parents and the original variety. The results of the fertilizer test in the course of three years (6 seasons) are given in table 5. Fig. 2 shows the panicle size of mutants and their hybrid lines. As can be seen in Fig. 3. variety Taichung 65 and three large panicle mutants tend to lodge at maturity in the double dosed fertilizer plot and erectoid mutant (fifth from the left in the picture) and their progeny lines would stand erect. The "Studentized Multiple Range Test" showed that in selected erectoid lines following hybridzation did not show any significant difference from the original in first crop season. However, in the second crop season, several selected erectoid lines of this cross yielded better than than the erectoid mutant of T-65 30-2-9 and original variety as well as the large panicle mutats.

Table 5. *Yield comparison of mutants of Taichung 65 on fertilizer response test.* (*2nd crop, 1961 to 1st crop, 1964*)

Mutant lines	Levels of fertilizer					
	first crop			2nd crop		
	0	1	2	0	1	2
Taichung 65 (CK)	100.0% (4,833.2kg/ha)	100.0% (5,455.4)	100.0% (5,313.7)	100.0% (3,891.6)	100.0% (3,931.6)	100.0% (4,085.1)
T 65 30-2-9	89.8	90.3	94.0	78.4	89.4	88.6
T 65 5.5-22-7	98.9	98.5	95.6	99.2	109.2	97.8
T 65 5.5-23-8	103.0	93.4	90.8	101.2	104.3	100.3
T 65 5.5-29-7	101.6	93.5	97.8	104.9	111.6	104.6
T 65 18-8	103.4	95.3	97.4	89.8	104.1	98.9
T 65 120-8	93.5	93.5	90.6	86.2	97.9	89.2
T 65 184-9	97.9	92.4	96.1	92.7	105.7	95.6
T 65 189-10	105.7	95.4	97.9	93.0	102.3	96.2
T 65 234-7	96.2	93.6	93.8	98.8	99.9	93.6
T 65 259-11	100.0	96.4	98.1	84.7	97.9	91.9
T 65 288-4	96.9	92.2	91.8	80.1	94.4	87.0
T 65 132-11	104.5	92.5	89.4	86.7	101.2	102.6

3. Further irradiation work in 1960.

From the results obtained so far, it is known that from the fertilizer-response test the mutant lines obtained from the polai or native varieties did not give significant high yield under heavy fertilization except Sh 30-21 (table 3). In addition to this, whenever heavy fertilization, especially nitrogen, is applied in rice field, rice blast disease *Piricularia oryzae* and other disease may become very prevalent. In 1959, Taichung 65 was treated with X-rays and gamma rays. Over 300,000 single plants of X_2 were planted in a heavily infected region for rice blast disease near Taichung. Unfortunately, not a single plant was selected which would be more resistant than the original variety. In 1960, Chianung 242 and Taichung 179 and two native varieties, I-kung-bau and Wu-ko-chin-yu grown extensively in Taiwan were again treated with X-rays and thermal neutrons. A number of erectoid mutant were obtained from native variety I-kung-bau. However, no satifactory mutants were found in the other three varieties irradiated likewise in the experimental field of Chung-Hsing University.

From 1962 another portion of the X_2 generation of above mentioned four varieties were planted in the experimental field of the agricultural experiment station Chia-yi which is about 100 km south of Taichung. From table 6, it can be seen that there are a number of promising lines that yielded better than their respective original varieties. It may be mentioned here that the mutant IKB 15-18 out-yielded it original variety by 35 and 48% in the first and second crop respectively. Further testing would verify the validity of these results.

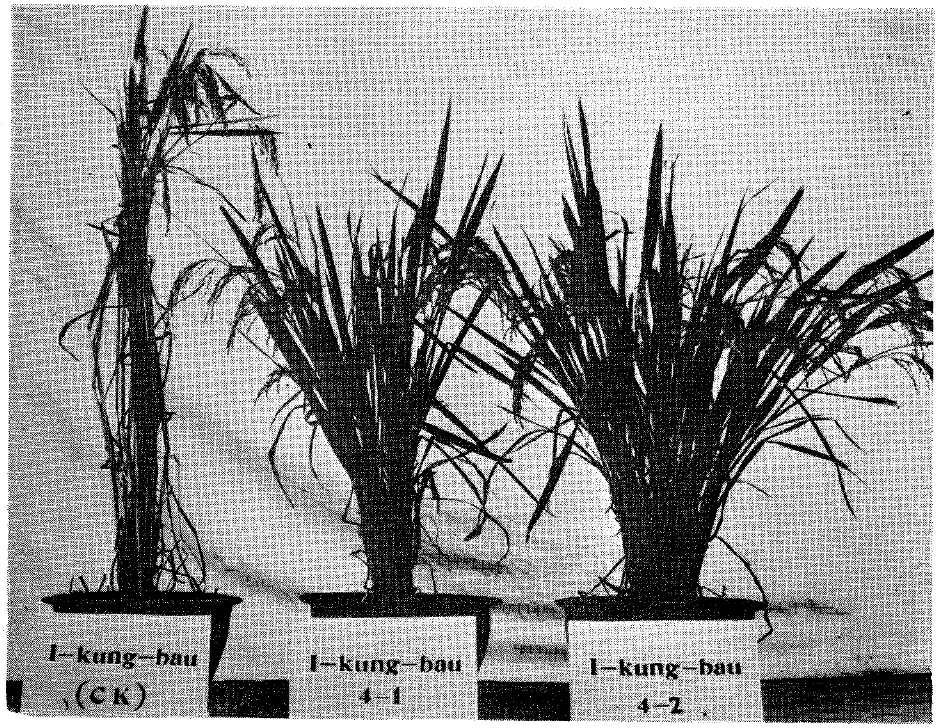

Fig. 1. Erectoid mutants induced from the variety of I-kung-bau.

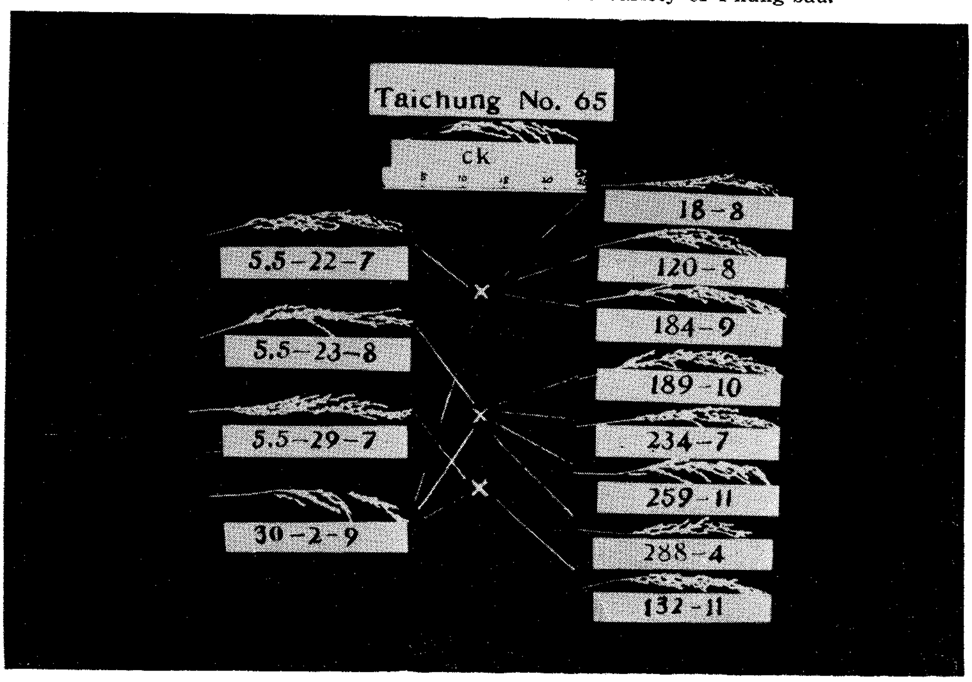

Fig. 2. Three large-panicle mutats (5.5-22-7, 5.5-23-8, 5.5-29-7) and erectoid mutant (30-2-9) induced from Taichung 65 with their progeny lines produced by different combinations of these two mutant types.

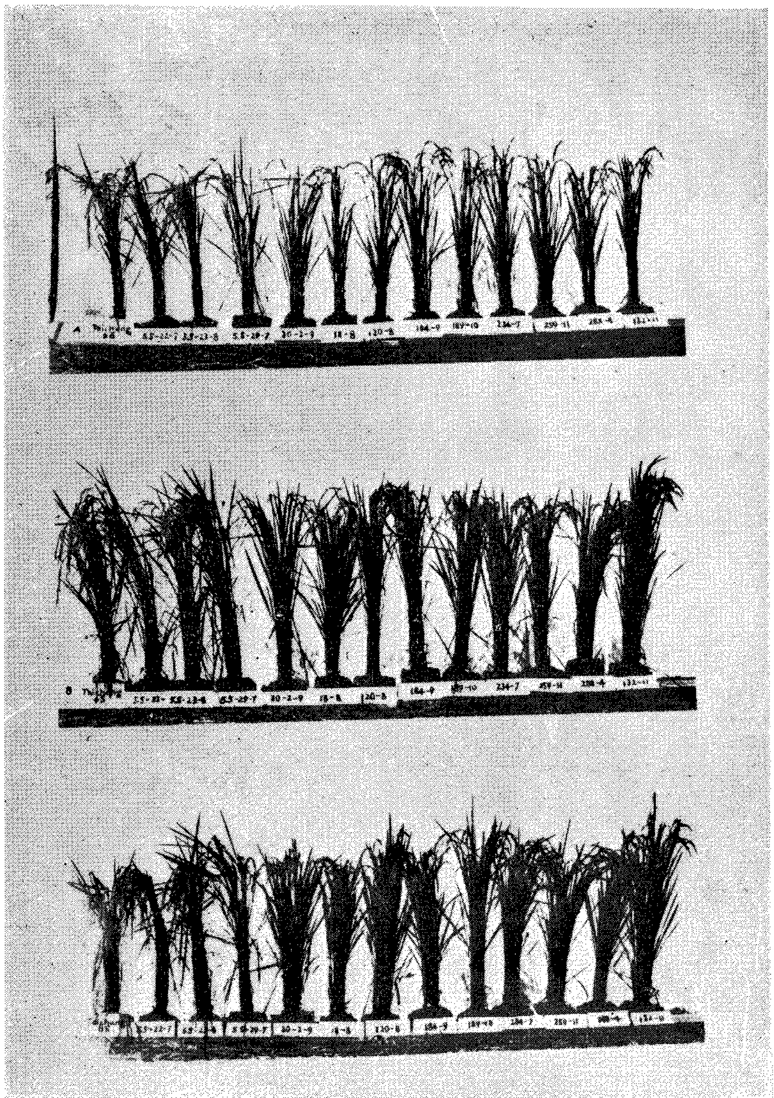

Fig. 3. Three photographs depicting the effects of fertilizer on line Taichung (far left No. 1), its fourr mutants (2 througe 5 from left 5.5-22-7, 5.5-23-8, 5.5-29-7, 30-2-9), and their eight progenies (18-8, 120-8, 184-9, 189-10, 234,-7, 234-7, 258-11, 288-4 and 132-11). Hpper: without fertilization; center: single dose; lower: double.

Table 6. *Comparison of promising lines' yielding capacities, 1964*

Mutants	First crop			Second crop		
	Plant height	No. of tillers	Yield	Plant height	No. of tillers	Yield
Chianung 242 (CK)	115.7 cm	8.9	100% (5,300 kg/ha.)	116.3 cm	12.0	100% (3,675 kg/ha.)
C 242 3-7	113.3	8.0	110.2	113.3	11.2	107.5
C 242 3-19	115.0	8.9	107.5	111.1	10.4	107.2
C 242 4-7	113.9	9.9	106.4	116.0	11.3	113.9
C 242 4-13	112.1	9.1	111.3	111.2	12.2	120.7
C 242 5-12	118.1	9.5	105.7	115.8	11.8	123.8
C 242 15-5	116.0	9.4	111.7	115.8	10.5	114.8
C 242 15-7	115.1	10.3	103.0	106.4	10.6	118.0
Taichung 179 (CK)	102.1	9.1	100% (4,960 kg/ha.)	102.5	11.6	100% (3,813 kg/ha.)
T 179 3-1	99.5	11.2	98.4	106.2	11.7	97.4
T 179 3-2	98.0	10.8	93.1	100.2	12.4	100.6
T 179 4-10	103.4	7.5	96.8	104.7	11.6	101.6
T 179 5-14	106.0	9.2	85.5	107.4	10.9	91.1
T 179 5-16	108.1	10.0	100.8	108.5	12.0	95.7
T 179 15-2	101.0	11.5	86.2	95.5	12.6	90.1
T 179 15-3	96.4	7.7	94.8	98.3	12.6	96.4
T 179 15-9	104.8	8.2	115.3	103.7	11.7	92.8
T 179 20-4	103.1	9.2	104.8	106.1	10.9	97.0
T 179 20-7	99.0	7.8	87.9	101.0	11.9	105.9
T 179 20-14	95.0	9.0	96.7	98.5	12.4	121.2
T 179 20-16	94.1	8.1	98.4	107.6	12.6	87.9
T 179 20-17	104.5	9.3	99.2	108.8	12.1	100.3
T 179 20-20	100.8	7.0	94.0	99.3	10.1	99.3
T 179 25-2	90.6	11.1	89.1	99.4	12.2	70.2
T 179 25-5	97.8	9.3	93.5	103.9	12.7	107.5
T 179 25-7	100.1	9.2	88.7	102.5	11.9	86.2
I-kung-bau (CK)	116.6	9.0	100% (3,800 kg/ha.)	106.7	12.1	100% (3,150 kg/ha.)
IKB 15-8	106.7	8.9	135.8	102.9	13.5	148.0
IKB 25-6	115.9	8.3	104.2	103.6	11.8	93.7
IKB 25-8	113.3	9.1	105.8	107.1	11.8	140.0
Wu-ko-chin-yu	125.8	7.5	100% (4,000 kg/ha.)	150.0	12.3	100% (3,475 kg/ha.)
WKCY 3-6	126.9	8.3	106.5	148.4	11.5	108.9
WKCY 3-7	129.0	7.8	98.5	152.1	12.2	90.4
WKCY 15-16	129.4	7.6	86.5	153.1	11.1	101.8

Discussion

The success of Gustafsson and this cooperators (1953, 1956, 1959, 1960 and

1963) used in breeding erectoid barley varieties by means of radiations and chemicals is very encouraging. In general, the erectoides is not susceptible to lodging and it may stand up well in fertile field, or in heavily fertilized field especially with nitrogenous. Hagberg *et al.* (1958) made genetic studies on erectoid barley; they found various multiple alleles located in twenty-two different loci. Their erectoids were crossed with the original variety. A simple Mendelian segregation was obtained with the normal type dominant over the erectoides. A pleiotropic effect of compact head was found to be associated with the decreasing of straw length. In our rice material, the erectoid-dwarf type of about 80 cm in height can be easily obtained both from the treatments of X-ray as well as from that of thermal neutron. When crossed with the normal plant, the inheritance of this type is readily found to be due to a single factor difference, the erectoides being recessive. Plants taller than the 80 cm and shorter than the originals are also frequently found, but they seem to be controlled by quantitative factors rather than by a single major gene (Sakai and Suzuki, 1964). The erectoids can be easily isolated, starting from the X_2 or the N_2 generation. They cannot compete well with the tall plants and therefore, they usually show poor growth in a mixed stands. In the F_2 generation of an erectoid-tall cross, the erectoids appear to be rather small in a mixed stand, possibly because they suffer from severe competition.

It seems that changes involving single factor are preferred to those involving two or more factors. Therefore a single variety may give rise to two or more different positive mono-factorial mutants from irradiation treatment. Variety Taichung 65 provides with the evidences. Mutants with large panicle and erectoid are obtained. Hybrid population of these two strains gives a di-hybrid segregation, while the other characters remain unchanged. Combination of these mutations with a variety having the same background seems to be rather easily done.

On the contrary, it seems that any a character which is conditioned by multiple factors will be difficult to be produced by irradiation. The blast resistance genes are not found in our experiment. Its main cause perhaps, is that the resistance is conditioned by multiple or complementary factors (Woo, 1965). Thus, even if a single blast-conditioning gene may be modified to be positively favorable, it will still not be enough to make this mutant resistant. Failure in obtain any resistant mutants to rice blast disease would make a sharp contrast to the results obtained by Cooper and Gregory's (1960) in finding resistant mutants to leaf spot disease (*Cercospora arachidicolar*) in peanuts and to the results of Konzak (1956) in obtaining resistant mutants to crown rust in oats as well as to the good result of Favret (1960) in getting resistance to mildew in barley. Their success was based on the change of physiological or biochemical components of the hostal plant by the influence of irradiation. Since there are different results obtained in different crops which are explanable by various theories, so it will be unreasonable to make a definite conclusion (Mikaelsen and Aastveit 1957).

Summary

From 1957-1960, twelve different rice varieties (*japonica* and *indica*) which were cultivated rather expensively in Taiwan recently were treated with different dosages of X-rays, gamma rays or thermal neutrons. Erectoid lines selected were found to be able to have significant increase in yield than their original variety as being tested in Taichung and Chia-yi. Some of these erectoid mutants were subjected to fertilizer-response tested and one erectoid line Sh 30-21 was found to be very responsive to the application of fertilizer rather clearly. None of the mutants obtained from Taichung 65 was found to be more resistant to rice blast disease after a large scale test in X_2 generation.

Some of the mutant lines were tested in the Island-wide Regional Test as being sponsored by the Provincial Government. Since thest mutants were not erectoids, they simply could not compete with the erectoid varieties used as checks. However, starting from the second crop of 1964, up to the first crop of 1965, some of the selected erectoid lines from irradiated native varieties as well as from source of erectoids selected by hybridizing erectoid mutant lines with other erectoid varieties were tested out in the Regional Tests in and around Taichung. Some did yield significantly higher than the erectoid varieties used as checks. They seemed to be of good promise. Some of the erectoid mutants obtaned from irradiated second crop varieties (native) which were short-day plants could be grown in the first crop, indicating that they were no longer sensitive to long-day photoperiodism.

By hybridizing the erectoid mutant and the large panicled mutant obtained from Taichung 65, some hybrid progenies were selected, which yielded better than their original variety and their parents. None of the early lines was found to be of any promise so far.

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臺灣水稻放射能育種的研究

李先聞　胡兆華　吳旭初

1957年到1960年間，應用 x，r 及熱中子三種放射線，處理十二種栽培比較普遍的在來稻及蓬萊稻種。經在臺中和嘉義兩地試驗的結果，誘變矮生種的產量可能超過原來的品種，這些誘變矮生種經過肥料試驗結果的證明，霜降突變種30—21號品系對肥料的反應很明顯，但是在抗病特性方面，臺中65號處理後代中，沒有選到抗稻熱病的誘變品系。

誘變品系曾經曾加農林廳舉辦的全省性在來稻區域試驗，因為當時參加的不是矮生系統，它們的產量都不如矮生稻，但是自1965年第二期作開始，幾種誘變矮生品系，在臺中地區舉行地方試驗，三種誘變矮生種的產量超過標準矮生種（臺中在來一號）。二期性品種經過放射能處理後，感光性損失，而能在第一期作栽培。

臺中65號大穗和矮生誘變品系間的雜種，有些品系產量比親本稍高。誘變早熟方面效果不甚明顯。

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APPENDIX

Results of Regional Test at Taichung District, 1st crop, 1965 (kg/ha.)

Mutant lines	Taichung		Luc-kon		Yuan-lin		Er-lin		Average	
	yield	%	yield	%	yield	%	yield	%	yield	%
Keh-tze 20-74	5,225	97.85	6,638	105.05	6,265	97.81	7,565	100.40	6,423.3	100.37
Shuang-chiang 30-21	5,430	101.69	6,882	108.91	6,760	105.54	7,705	102.25	6,694.3	104.60
I-kung-bau 4-2	5,315	99.53	6,506	102.96	6,050	94.46	7,870	104.44	6,435.3	100.55
TN No. 1 × Sh30-21-44-5	5,645	105.71	6,844	108.31	6,620	103,36	7,685	101.99	6,698.5	104.67
Liu-chow 25-108-30	4,825	90.36	5,794	91.69	5,600	87.43	7,115	94.43	5,583.5	87.24
Taichung native No. 1 (CK)	5,340	100.00	6,319	100.00	6,405	100.00	7,535	100.00	6,399.8	100.00