CONTROL OF SEED BORNE DISEASES BY RADIOACTIVE IRRADIATION[1]

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Introduction

Radioactive irradiation has been used in the field of plant pathology for inducing mutations both in plants and pathogens. Mutations in plants are desired because new resistant varieties are sought, while those in pathogens can lead to the appearance of useful physiological races of high pathogenicity, etc. Many phytopathologists, for example, Rodenhiser *et al.* (1941), Anderson *et al.* (1956), Flor (1957) and Schwinghamer (1957) reported that radioactive irradiation could inhibit the germination of conidia and induce the mutation of causal organism at a certain dose of irradiation. Threinen *et al.* (1959) worked on hybridization between radiation-induced mutants of two varieties of *Diaporthe phaseolorum,* indicated that relative pathogenicity appeared to be definite in the parent types, but less so in their mutants. Pearson *et al.* (1948) reported that *Geotrichum, Microsporum gypseum, Nigrospora, Sporotrichum schenckii,* etc. were seriously effected by X-ray irradiation, and they tabulated numerous pathogenic and nonpathogenic fungi which survived exposure to radioactive phosphorus, iodine, and high voltage X-ray without alteration in their morphology or pathogenicity. Timanick *et al.* (1951) indicated that ultraviolet irradiation of cultures stimulated or inhibited the formation of perithecia of *Diaporthe phaseolorum* var. *batatatis.*

In the use of radioactive isotopes for tagging fungi, Wheeler (1952) reported that *Glomerella cingulata* appeared to be slightly retarded at activities greater than 10 microcuries/ml. No effects upon growth rate, sporulation, or morphology which could be attributed to radioactivity were observed in cultures grown for 3–7 days on media containing radiocarbon. Levin and Levine (1917) conducted tests which indicated that radioactive irradiation might play a part in the

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therapy of plant disease. The work of Rivera in 1962 confirmed these results. Beraha *et al.* (1959) denoted that storage and shelf life of food materials could be extended by the use of gamma radiation. Waggoner and Dimond (1959) denoted that ionizing radiation both increased and decreased resistance of 5 to 6 week old Bonny Best tomato plant to *Fusarium* wilt.

According to the above references, it is clear that radioisotopes are widely used in plant pathological studies, but the reports about their direct use in the control of plant disease by means of radioactive irradiation is, however, limited especially with regard to seed borne diseases. Plant disease control by fungicidal treatments is not yet entirely satisfactory. So other methods such as radioactive irradiation for the control of seed borne disease are worth investigating. The present paper deals with the possible effect of radioactive radiation upon causal organisms to determine whether or not the seed borne diseases can be controlled by means of radioactive irradiation.

Materials and Methods

Seed samples of 3 seed borne diseases and pure cultures of their causal organisms were used in this investigation, *i. e.* Spot blotch of barley (*Cochliobolus sativus* (Ito & Kurib.) Drechsl.), Brown spot of rice (*Cochliobolus miyabeanus* (Ito & Kurib.) Dickson), and Purple stain seed of soybean (*Cercospora kikuchii* (Matsu. & Tomoyasu) Gardner).

The diseased seeds mentioned above were irradiated under gamma radiation obtained from the source of Co^{60} (1000 curie unit) with different dosages and varying in time periods by external radiation. The radiation dosages ranged from 5000 to 60,000 γ (roentgen) except for the higher voltage of 80,000 γ which was used on spot blotch of barley. The irradiated seeds were used both for isolation of causal organisms and for planting to observe seed germination and disease development. Following irradiation the diseased seeds were sown in pots containing sterilized soil. Final observations were made after emergence. To determine the influence of irradiation on growth of the causal organisms, the irradiated seeds infected with each disease were placed for isolations in Petri dishes containing potato sucrose agar. The Petri dishes mentioned above were kept in the incubators at the temperatures 25°C, 28°C, and 29°C. respectively. In the tests of brown spot of rice, the irradiated seeds were divided into two groups, namely, lightly diseased seeds, and heavily diseased seeds. The former were used for planting for the observation of seed germination and disease development. The latter was used for the isolation and the spore germination since there are so many spores attached on grains that they can be washed off. The spore suspension thus made was dropped on the slide previously prepared for germination test. Counting was made under the microscope after 24 hours of incubation.

Experimental Results

A. *Spot Blotch of Barley*

1. The Effect of Radioactive Isotope on Barley Seed

The results of this experiment are given in detail in Table I which shows that germination of the seeds was inversely proportional to the dose of radiation. At à dose of 80,000*r*, there was a noticeable inhibition of seed germination, whereas untreated seeds showed the higher percentage of germination than those treated with any dose. On the other hand, disease development was similarly influenced by a relatively high dose irradiation ranging from 40,000 to 80,000 *r*.

Table 1. *Influence of Radioactive Irradiation on Barley Seed Germination and Disease Development*[a]

Dosage[b]	Percentage[c] of Germination	Disease Development[c]			Mutation of Host (Barley)[c]
		Stands Surveyed	Stands Disease	Percentage of Diseased Stands	
0 (CK)	96	222	31	13.90	N[d]
5,000	94	271	30	11.09	N
10,000	94	265	34	12.80	N
20,000	70	279	16	5.70	N
40,000	69	149	9	6.04	M[e]
60,000	3				M

[a] Seeds were sown in pots containing sterilized soil.
[b] Gamma radiation from Co^{60}.
[c] Final observations were made 5 days after barley emergence.
[d] Normal growth.
[e] Morphological variation.

2. Radioactive Irradiation to the Causal Organism of Spot Blotch of Barley

The results of the experiment shown in Table 2 indicate that each dose used in this experiment was ineffective in retarding growth of the fungus colonies on potato sucrose agar. It confirms, however, that the minimum lethal dose of *Cochliobolus sativus* is beyond 80,000 *r*. But observation on growth of the colonies obtained from the isolations evidently indicated that the mutations of the causal organism were detectable under the dose 10,000–80,000 *r*. The mutant was not detected at a dose of 5,000 *r*. Variant isolates of *C. sativus* obtained from gamma irradiation and their sources are given in Table 3. The differences between mutants and normal isolates are given in detail in Table 4 and Table 5.

Table 2. *Frequency of the* ***Cochliobolus sativus*** *Isolated from the Irradiated Seeds*[a]

Irradiation dosage (γ)[b]	Total Number of grains tested	Microorganisms isolated[c]			Seeds free from Microorganism
		C. sativus	Bacteria	Other fungi	
0 (CK)	12	9	1	—	2
5,000	16	10	—	2	4
10,000	18	13	—	2	4
20,000	18	16	—	—	2
40,000	19	11	—	1	7
60,000	19	11	—	1	7

(a) Potato sucrose agar plates used for isolation were kept in incubator at 29°C.
(b) See Table 1.
(c) The growth of the microorganisms were observed after 4 days incubation.

Table 3. *Variants of* ***Cochliobolus sativus*** *Obtained from Gamma Irradiation and Their Sources*[a, b]

Isolated mutant	Origin
V-3, V-4, V-6	Isolated from 20,000 γ irradiated seeds
V-7, V-8	Isolated from 10,000 γ irradiated seeds
V-10	Isolated form 80,000 γ irradiated seeds
V-12, V-14	Isolated form 40,000 γ irradiated seeds
V-91, V-92	Isolated form 80,000 γ irradiated seeds

(a) Incubation temperature was at 29°C.
(b) Potato sucrose agar was used in the experiment.

According to the results obtained it is shown that the morphology and growth of the colonies, and sporulation of each mutants differ from each other (see Fig. 1–2). It is clear by comparison with non-irradiated samples that sporulation and growth rate of most of the mutants were inhibited by irradiation. On measuring the size of spores, it was found, however, that there were variations in each mutant, depending upon the dose of 10,000–80,000 γ irradiated. According to the characteristics of each mutant observed, four types of mutants can be categorized, *i.e.* (a) light type: Colony light in color, sporulation few, V–8 and V–10 are included. (b) sterile type: Sporulation very few, V–91 is included. (c) small type: Small type spores are produced, V–92 is included.

(d) distortion type: Malformation of spores and hyphae are produced in this type, sporulation few, V-4 and V-12 are included.

Table 4. *The Comparison of Colonial Variation of* ***Cochliobolus sativus*** *Obtained from Irradiation Under the Source of* Co^{60}[(a)]

Mutant[(b)]	Color of Colony	Margin of Colony	Surface of Colony	Aerial Hypha	Relative amount of Sporulation[(c)]	Growth in Diameter (mm)[(d)]
CK	Olivaceous Black	Undulate	Dark grayish olive		+++++ +++++ +++++ +++++	60.0
V-3	Olivaceous Black	Undulate	Dark grayish olive	Little, near the center of the colony	+++++	47.7
V-4	Olivaceous Black dark Grayish Olivaceous	Undulate	Aerial mycelium covers the surface of colony	Grayish olive	++++	48.5
V-6	Olivaceous Black	Lobate	Aerial mycelium white, near the margin of the colony. The center of the colony with sclero-like mycelium, sooty black	White, smoke grey near the margin	+++++	12.5
V-7	Olivaceous Black	Lobate			+++++	33.2
V-8	Black near the center Dark olive	Undulate	Center part black margin iron gray	Little	+++++	51.2
V-10	Black to grayish olive	Lobate			+++++	30.2
V-12	Black	White	Pale neutral gray	Aerial hyphae short, more pale neutral gray		11.5
V-14	Black	Lobate				12.5
V-91	Fascous to grayish	Entire to lobate	White, whitish sclerolike mycelium occurs near the margin	More	+++++	33.2
V-92	Olivaceous Black		Iron gray	More and tight	+++++ ++	16.5

(a) Potato sucrose agar plates used for the growth of colonies were kept in the incubator at 29°C.
(b) See Table 3.
(c) Number of the spores were counted in comparison with the check sample.
(d) Averaged by 5 replications after 4 days incubation.

Table 5. *Length and Width of Spore of Various Mutants*[a]

Mutants[b] / Measurement	V-6	V-4	V-3	V-8	V-91	V-92	V-12[c]	V-14[c]	V-7
Average Length μ	85.1	40.4	114.4	132.4	54.8	67.5	—	—	98.9
Average width μ	27.3	19.5	44.5	40.3	24.7	26.3	—	—	33.1

[a] The spore size given was the average size of 100 spores.
[b] See Table 4.
[c] No sporalation.

B. *Brown Spot of Rice*

1. *The Effect of Radioactive Isotope on Rice Seed*

The irradiated mildly-diseased seeds were sown in pots containing sterilized soil for the observation of seed germination and disease development. In general, no distinguishable influence was detected in low dose of irradiation. The results of seed germination given in Table 6 are the average of three tests.

Table 6. *Influence of Radioactive Irradiation on Rice Plants and Its Effect on Control of Brown Spot Disease*

Dosage[a] (γ)	Germination[b]			Disease development[b]			Reaction of host
	No. of seeds sowed	germination seeds	percentage of germination	Seedlings surveyed	diseased seedlings	percentage of disease seedling	
0 (CK)	50	36	82	20	0	0	N[c]
5,000	50	45	90	20	0	0	N
10,000	50	39	78	20	0	0	N
20,000	50	45	90	20	0	0	N
40,000	50	40	80	20	0	0	N
60,000	50	30	60	20	0	0	M[d]

[a] See Table 1.
[b] Final observations made 15 days after emergence.
[c] Normal growth.
[d] Morphological variation.

It showed that the influence on percentage of seed germination was not clearly decreased by gamma irradiation at a dosage from 5,000 to 60,000 γ. At a dosage of 5,000, and 20,000 γ the percentage of seed germination was higher than the check sample. It seemed that gamma irradiation under the dose of 5,000–60,000 γ might not inhibit the germination of the seeds. But on observation of growth of the host plants it was seen that the irradiation under the dosage of 60,000 γ or more can lead to the induction of morphological variations. The variant of the host obtained from irradiation in general is dwarfed in form.

2. Influence of Radiation on the Pathogen

The results of the experiment are shown in Table 7 and Table 8. The

Table 7. *Influence of Radioactive Irradiation on the Growth in Diameter (cm.) of the Colony of* ***Cochliobolus miyabeanus***[a, b]

Dosage (γ)[c] \ Period of incubation (days)	3	4	5[d]
0 (CK)	2.9	4.6	5.8
5,000	2.7	3.8	4.5
10,000	2.6	3.7	4.6
20,000	2.6	3.4	4.3
40,000	2.4	3.2	4.0
60,000	2.2	3.2	4.2

(a) Diameter of the colonies were averaged by 5 replications.
(b) Potato sucrose agar plates used for the growth of colonies were kept in the incubator at 28°C.
(c) See Table 1.
(d) The average decrease in diameter observed indicates that the diameter size decreases with the increasing amount of irradiation.

Table 8. *The Comparison of Colonial Variation of* ***Cochliobolus miyabeanus*** *Obtained from Irradiation under the Source of* Co^{60}[a]

Dosege[b]	Color of colony	Margin of colony	Surface colony	Aerial Hyphae	Relative amount of Sporulation[c]
0 (CK)	Center, gray brown in color; outer part, dark brown in color	Filamentous	Aerial hyphae	Profuse	++
5,000	Center, brown in color; outer part, light brown in color	Coarsely granular	Aerial hyphae rigid	Profuse	+++++
10,000	Center, gray brown in color; outer part, light gray	Rhizoid	Aerial hyphae tight	Ditto	+
20,000	Center, light gray in color; outer part, dark gray in color	Filamentous (regular)	Ditto	Ditto	+
40,000	Center, white; outer part, light gray	Filamentous	Aerial hyphae middle	Moderate	++
60,000	Gray in color	Curled	Aerial hyphae few	Few	+

(a) Potato sucrose agar plates were used for growth of the colonies.
(b) See Table 1.
(c) Number of the spores were counted for comparison with the number on the check sample.

data suggest that some variations appeared on growth and morphology of the colonies of *Cochliobolus miyabeanus* (see Fig. 3). The color of the colonies, in general, became light after irradiation.

The colonial growth of the causal organism isolated from heavy diseased seed was retarded or eradicated respectively following irradiation at 5,000–60,000 r.

3. Spore Germination

The result is shown in Table 9. The percentage of germination though with differences at 5,000–40,000 r shows that there was no noticeable inhibition following irradiation. But at progressively higher doses the percentages of spore germination was proportionally decreased. However, the spore germination was reduced by radiation at the dosage of 60,000 r and increased somewhat at the dosage of 10,000, 20,000 and 40,000 r respectively.

According to the reports of Louis Beraha *et al.* (1959) that *Pencillium digitatum* and *P. italicum* were resistant to radioactive irradiation. Spore germination was inhibited at the dosage of 940,000 r and the *Rhizopus nigricans* needed more radiation dosage for inhibition of spore germination. The minimum lethal dose for *Cochliobolus miyabeanus* was not worked out in this investigation.

Table 9. *Influence of Radioactive Irradiation on the Germination of Conidia*[a]

Dosage[b]	Number of conidia counted[c]	No. of germinated conidia[c]	Percentage of Germination[c]
0 (CK)	450	226	50.2%
5,000	450	326	72.2
10,000	450	308	68.4
20,000	450	269	57.8
40,000	450	227	50.4
60,000	450	190	42.0

[a] Slide method was employed.
[b] See Table 1.
[c] Counting was made under the microscope 24 hrs. after incubation.

C. *Purple Stain Seed of Soybean*

1. The Effect of Radioactive Isotope on Soybean Seed

The results of the experiment are given in detail in Table 10, 11 and 12. Data shown in Table 10 which evidently show that the percentage of germination decreased as the dose of irradiation increased. High level doses of radiation inhibited the seed germination, particularly in the dose of 60,000 r.

Some variations appeared, especially at the dose of 40,000 and 60,000 γ. The leaves of the mutant plants were rugose, small, narrow in form and light-green in color, and they looked like the rosette of soybean caused by the virus (see Fig. 5). At the same time differential irradiation produced variations in the growth of the whole plants (see Fig 6). Data shown in Table 11 indicate that the purple spot might appear on the cotyledons 12 days or less after emergence, but that the variations had no significant influence on eradication or inhibition of the disease development.

Table 10. *Percentage of Germination of Purple Stain Seeds of Soybean after Irradiation*

Dosage[a] (γ)	Number of Seeds Sowed	Number of Germinating Seeds	Percentage of Germination[b]	Mutation of Host
0 (CK)	100	96	96	N[c]
5,000	100	92	92	N
10,000	100	92	92	N
20,000	100	84	84	N
40,000	100	20	20	M[d]
60,000	100	3	3	M

[a] See Table 1.
[b] Observation was made 12 days after emergence.
[c] Normal growth.
[d] Morphological variation.

Table 11. *Disease Development as Observed on Cotyledons of Soybean Plant*[a]

Dosage[b] (γ)	Stands counted[c]	No. of Diseased cotyledons[c]	Percentage of disease[c]
0 (CK)	100	7	7
5,000	100	5	5
10,000	100	5	5
20,000	100	6	6
40,000	10	0	0
60,000	3	0	0

[a] Soybean seeds were seeded in pots containing sterilized soil.
[b] See Table 1.
[c] Final obervations were made 12 days after emergence.

2. The Reaction of Pathogen to Radioactive Irradiation

The results given in detail in Table 12 suggest that the irradiation may lead to the induction of some variation on growth of the colonies. The growth of the colonies isolated from nonirradiated seeds, is more rapid than that of the irradiated samples. It is evident that irradiation could inhibit the growth of the colonies especially at the dose of 60,000 γ. At a does of 60,000 γ an induction of variation on the morphology of the colonies is effected. On the other hand, purple pigment formation of the causal fungus is reduced by the irradiation (see Fig. 4). The purple pigment is distributed around the outer part in the margin of the colony but it accumulates only under the colony in irradiated ones.

Table 12. *The Influence of Radioactive Irradiation on Colonial Growth (cm.) of* ***Cercospora kikuchii***[a]

Dosage[b] (γ) \ Incubation period (days)	4	5	6	7	8	Mutation of colony
0 (CK)	1.40[c]	1.80	2.30	3.20	3.80	N[d]
5,000	1.40	1.80	2.20	2.70	3.10	N
10,000	1.50	1.70	2.40	2.90	3.30	N
20,000	1.45	1.80	2.30	2.85	3.30	N
40,000	1.40	1.75	2.30	2.80	3.25	N
60,000	1.20	1.60	2.00	2.50	2.70	M[e]

[a] Petri dishes containing potato sucrose agar were used for the growth of the colonies incubated at 25°C.
[b] See Table 1.
[c] Averaged by 5 replications.
[d] Normal growth.
[e] Morphological variation.

3. *Sporulation*

Since no suitable medium for the sporulation of *Cercospora kikuchii* has been found, an alternative method was designed for this test. After surface disinfection, irradiated diseased-seeds were placed into a sterilized moist chamber for the observation of sporulation. The moist chamber was kept in incubator at the temperature of 25°C. Four days later, observation was made. The result indicated that radioactive irradiation has no influence on sporulation of *Cercospora kikuchii*.

Discussion and Conclusions

According to the author's experimental results, it is evident that all 3 host plants exhibit some mutations such as lower germination percentage and multiformation were observed in plants from treated seeds. Waggoner and Dimond (1952) determined the effects of ionizing radiation on both the tomato wilt pathogen, *Fusarium oxysporum* f. *lycopersici* and the host plant. Since *Fusarium* is considerable more resistant to ionizing radiation than the host, a dose of $6.6\times10^6\,r$ is needed to kill fifty per cent of the spores tested, however the host plants were killed by a dose of 100,000 r. It is predicted that therapy of *Fusarium* wilt can not be effected with a source of radiation external to the host. This prediction is verified by experiments using gamma radiation from Co^{60}.

Radioisotopes can possibly accumulate in diseased tissue either as a result of metabolic accumulation or as a result of mechanical stoppage of translocation processes. Therefore therapy may be possible when a radioisotope is accumulated in diseased tissues to such a degree that death of the parasite is favored while injury to the host is minimized. As possibility has to be explored, the distribution of radiophosphate is measured in healthy and diseased tomato plants to determine what amount of radioactivity can be used without interfering with the growth of a healthy plant. Waggoner and Dimond found that irradiation was more damaging to the plant than to the pathogen, so they concluded that the therapy of *Fusarium* wilt by internal sources of radiation seemed unlikely. Because of this radiotherapy of seed borne disease is, indeed, of no significance. However Beraha *et al.* (1959), etc. obtained an effective control of fruit rotting by irradiation which led investigators to seek further knowledge on control of plant diseases by radiotherapy.

Beraha *et al.* (1959) used the factors influenced by gamma radiation to control the decay of lemons and oranges. Their investigations demonstrated that a delicate balance exists between the amount of gamma radiation providing an extension of the shelf life of inoculated fruit and the amount producing radiation injury. The actual mechanisms producing injury to plant tissue and inactivation or death of fungi are not well known. In comparison of the results obtained by Beraha (1959) and Waggoner (1952), made it clear that resting organs of the fruits are capable of more resistance to ionizing radiation than other organs of the plant. Thus there appears some possibility that radioactive irradiation controls the diseases of fruits. However, the results obtained from this investigation indicate radioactive irradiation of diseased seeds to be less satisfactory than was hoped. It may be concluded that direct control of seed borne disease by means of radioactive irradiation is difficult to carry out at least at the present time because of the damage done to the host plant.

Flor (1957) and Schwinghamer (1957) reported that several variants of *Melampsora lini* were obtained by X-ray, thermal neutrons and ultra-violet irradiation. Among them, the virulency of several variants, however, decreased, while that of others increased. The author, in testing the effect of irradiation on causal organisms of each disease used in this investigation, also obtained several variant isolates. He wishes to point out that gamma radiation may lead to some variations of the causal organisms following certain dosages. If causal organisms were concealed on the seeds it is possible that radioactive irradiation would produce some new strains of them. The formation of new strains or variants of causal organisms is of much significance in the work of plant protection and varietal improvement. From the point of plant disease control, studies on pathogenicity of variants of the causal organism obtained by gamma radiation is of interest to plant pathologists.

Summary

The present paper dealt with the results of studies on the control of seed borne disease by radioactive irradiation. The seed borne diseases and pure culture of their causal organisms were used in this investigation, *i.e.* spot blotch of barley (*Cochliobolus sativus* (Ito & Kurib.) Drechsl.), brown spot of rice (*Cochliobolus miyabeanus* (Ito & Kurib.) Dickson), and purple stain seed of soybean (*Cercospora kikuchii* (Matsu. & Tomoyasu) Gardner). The diseased seeds mentioned above were irradiated under gamma radiation obtained from the source of Co^{60} with different dosages by external radiation.

The results obtained from this investigation indicated that high dosage level radiation could inhibit the germination of seeds. In general, the pathogens were more resistant to radioactive irradiation than their respective hosts. The mutants of tested pathogens were induced by irradiation. The minimum lethal dosage was not worked out owing to the lack of high dosage level source. 9 mutants of *Cochliobolus sativus* were induced. These mutants exhibited differences in growth character and morphology of spores. The conidia of *Cochliobolus miyabeanus* germinated freely after having been exposed to dosage up to 60,000γ dosage level. The purple pigment from *Cercospora kikuchii* was visible around the outer part of colonies obtained from non-irradiated seed whereas it could be found only under the colonies of irradiated ones.

The influence of radioactive irradiation on the growth of soybeans was very significant. The leaves of variant plants of soybean were rugose, small, narrow and light green in color. The growth and podding of an irradiated soybean plant decreased in inverse proportion to the increase of the irradiation dosage. The author's results confirmed that seed borne diseases could not be controlled by means of radioactive irradiation.

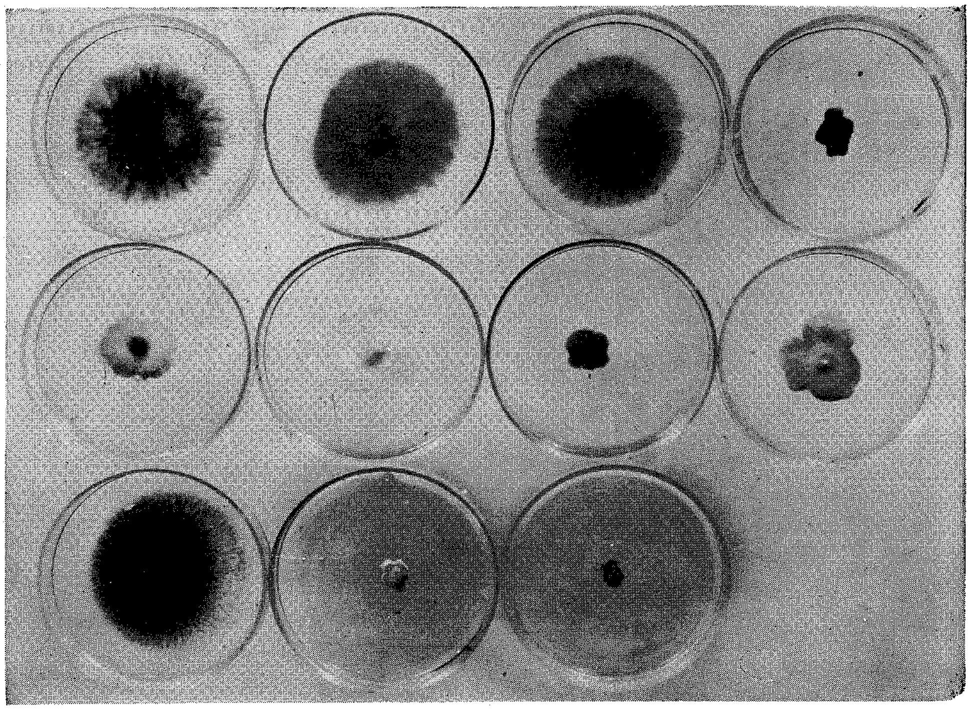

Fig. 1 Colonial Growth of the Variants of *Cochliobolus sativus* Obtained from Radioactive Irradiation.

upper layer from left to right: V-3, V-4, V-5, V-6,
middle layer from left to right: V-7, V-92, V-91, V-10,
lower layer from left to right: CK, V-12, V-14.

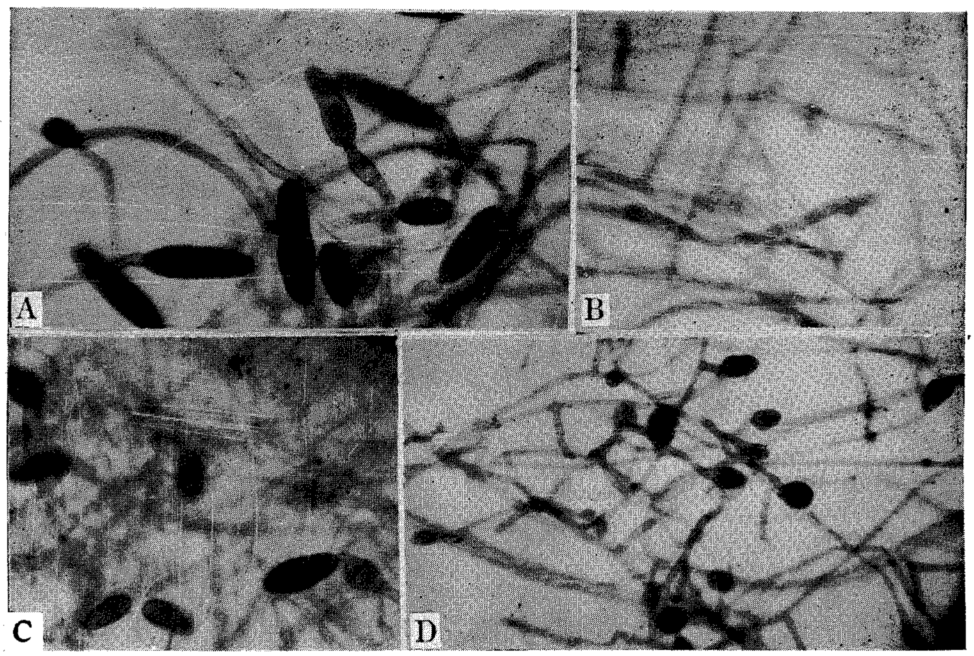

Fig. 2 Comparison of Four types of Variants of *Cochliobolus sativus* Obtained from Radioactive Irradiation.

A. Light type, B. Sterile type, C. Small type, D. Distortion type.

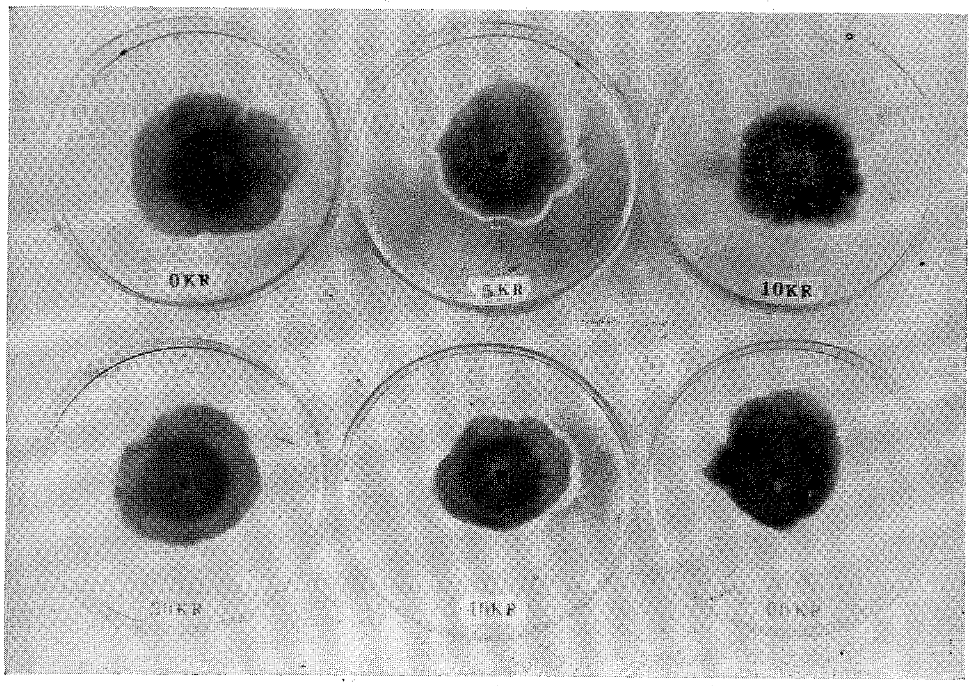

Fig. 3. Growth and Colonial Variation of *Cochliobolus miyabeanus* following Radioactive Irradiation.

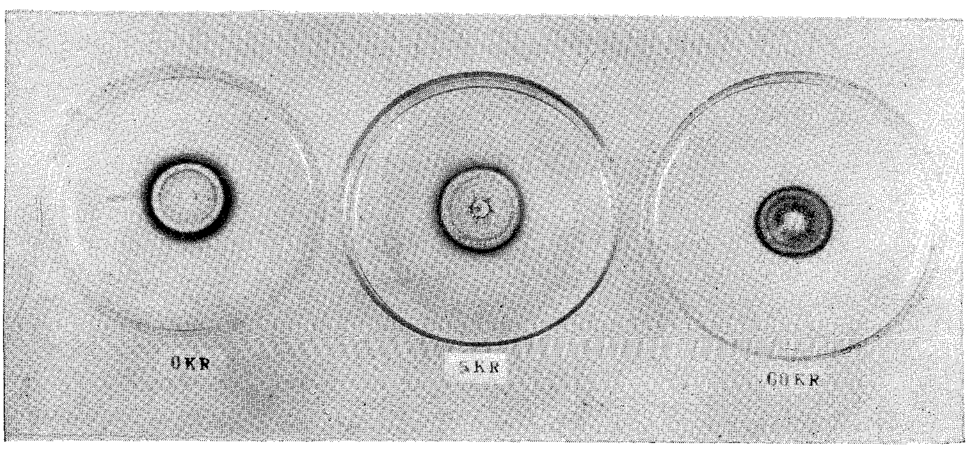

Fig. 4. Purple Pigment Formation of *Cercospora kikuchii* following Radioactive Irradiation.

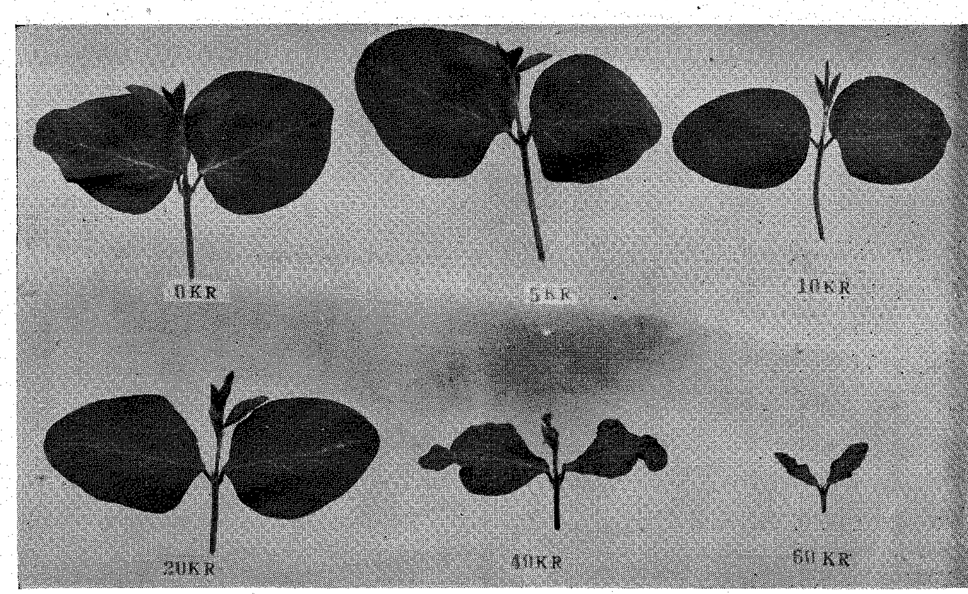

Fig. 5. Growth of Soybean Seedling Following Radioactive Irridiation (Only top leaves are shown).

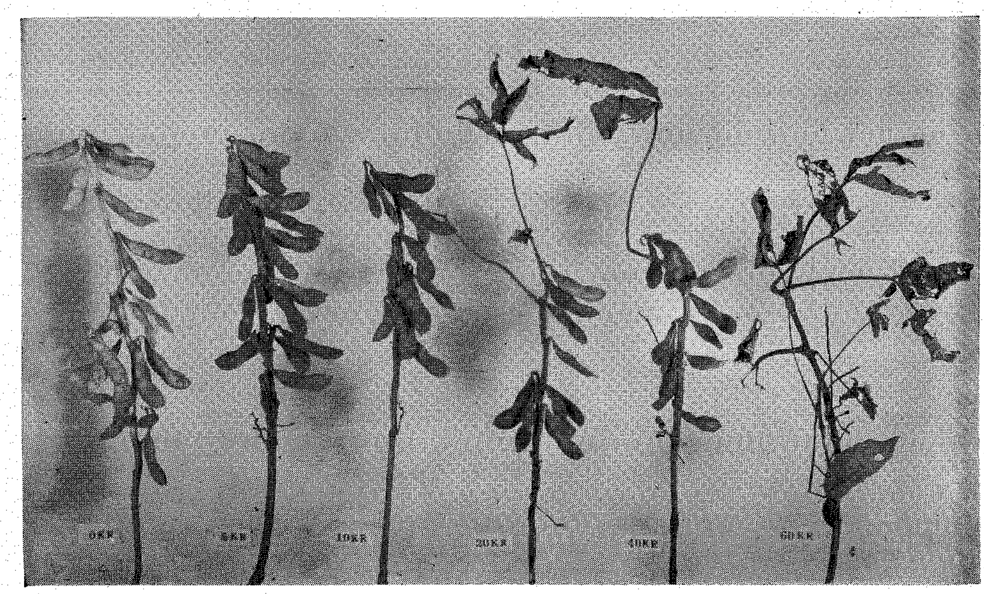

Fig. 6. Fruition of Soybean Following Radioactive Irradiation of Diseased Seed.

放射線照射對種子傳染病害防治之研究

羅 清 澤

由本試驗之結果，獲悉菌類對於放射線之耐性頗高，此與 Waggoner 與 Dimond，Beraha *et al.* 及 Pearson *et al.* 等，先後報告之結果相符合。依 Waggoner 與 Dimond 二氏就蕃茄萎凋病菌 (*Fusarium oxysporium* f. *Lycopersici*) 之試驗結果，可知殺死半數胞子所需之輻射量為 $6.6\times10^6\,\gamma$。然寄主植物之耐性則低，一般平均在 100,000 γ 左右時，即已相繼死亡。

本文之供試材料為大麥，水稻及大豆之罹病種子，在 60,000 γ 之低線量時，即開始發生變異，如發芽率之銳減及畸形植株之出現等 (見圖5-6)。由此可知，在目前若將輻射線用作直接防治植物病害時，則不易成功。

病原菌於輻射線之感應試驗過程中，出現變異菌株若干 (見圖 1-4)。利用適度之輻射線誘變法，可使病原菌產生變異，而由變異之新菌系，其生理性質或病原性必有不同，此在抗病育種之抗病性品種檢定上，有其廣泛應用之價值。

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