Radiobiological Studies in Plants, VI

Effects of Radiations from the Nuclear Reactor, JRR-1, on Dry Seeds of Wheats and Oats¹⁾

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In recent years many works have been reported concerning the biological or genetical effects of various radiations on higher plants. The present authors and their co-workers in this laboratory have also been undertaking radiobiological studies in some plants, and a part of the result obtained was already reported (NISHIYAMA *et al.* 1959, *etc.*). The present study was conducted in order to know disturbances of plant growth by ionizing radiations from the Japan Research Reactor No. 1 (JRR-1) of the Japan Atomic Energy Research Institute, and to compare biological effects of neutrons, X-rays, and gamma-rays.

Materials and Methods

Dry seeds of *Triticum monococcum* var. *vulgare* KÖRN. (2x), *T. dicoccum* SCHÜBL. (4x), *T. persicum* L. (4x), *T. vulgare* VILL. var. *Shinchunaga* (6x), *T. vulgare* VILL. var. *Iga-chikugo* (6x), *Aegilops squarrosa* L. (2x), *Avena strigosa* SCHREB. (2x), *A. strigosa* SCHREB. (4x, autotetraploid), *A. barbata* POTT (4x), *A. sativa* L. (6x), and *A. sativa* L. var. *Kanota* (Hc-541) (6x) were used in the experiments. The seeds were selected from those harvested in 1958 to be of uniform size and weight in each species.

The irradiation treatment with neutrons was performed in the beam hole No. 16 of JRR-1. The radiations in this hole were mainly thermal neutrons, with contaminating resonance neutrons, fast neutrons, and gamma-rays. The dosimetry of the thermal neutron fluxes had already been made by the personnel of the Japan Atomic Energy Research Institute, and the dose rate of the contaminating resonance neutrons had also been informed by them to be about one fifth of that of the thermal neutrons (cadmium ratio 6, JRR-1 OPERATION GROUP 1958). The exact dose rate of the fast neutrons in this hole was not determined, but it was estimated not to be so high. The dose rate of the contaminating gamma-rays was measured by KONDO (1960), whose data are used in this paper.

Irradiation experiment I

The first experiment was carried out in December, 1958. Dry seeds of five *Triticum* species and four *Avena* species, sealed in thin polyethylene bags, were put in the provided

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polyethylene capsule (3 cm in diameter and 8 cm in length), and thrown into the most interior of the beam hole No. 16 by compressed air. The dosage of each radiation applied to the seed was calculated as follows:

Exposure number	Thermal neutrons ($\times 10^{11} n \text{ th/cm}^2$)	Resonance neutrons ($\times 10^{11} n \text{ res/cm}^2$)	Gamma-rays (r)
(1-1)	0.92	0.18	41
(1-2)	9.20	1.80	410
(1-3)	92.00	18.00	4100
(1-4)	—	18.00	4100

Seeds in (1-1) and (1-2) were exposed for 16 and 160 seconds, respectively, when the reactor was being operated at 0.5 kW. On the other hand, those in (1-3) and (1-4) were treated for 20 seconds at 40 kW. In the case of (1-4), seeds were covered with 0.5 mm cadmium filter to protect from the beam of thermal neutrons. For the convenience of expression, the dosages of JRR-1 radiations in treatments with or without Cd-filter will be shown by those of resonance neutrons or thermal neutrons, respectively.

In each treatment 30 seeds were used for each species. Irradiated seeds were sown in the steamed soil in wooden flats which were placed in the greenhouse. Germination rate (counted as germinated if coleptiles were 3 mm or more in length) and seedling height were measured at 10 days after sowing. Also, seedling height, survival rate, and the length and width of the first, second, and third leaf-blades were measured 50~60 days after sowing when the third leaves grew into maximum length.

No significant difference was observed in germination rates between the non-irradiated seeds and the irradiated seeds with $9.2 \times 10^{10} n \text{ th}$, $9.2 \times 10^{11} n \text{ th}$ or $1.8 \times 10^{12} n \text{ res/cm}^2$. However, the higher dosage of irradiation with $9.2 \times 10^{12} n \text{ th/cm}^2$ caused a distinct decrease of germination rates in diploid and tetraploid species of *Triticum* and *Avena*, except in *T. persicum*. That is, the percentages of germination in *T. monococcum* (2x), *T. dicoccum* (4x) and *T. persicum* (4x) were 63.0, 72.4 and 96.6 respectively, and those of *A. strigosa* (2x) and its autotetraploid were 26.7 and 46.5 respectively, taking the value of each control as 100. However in the hexaploid species including *T. vulgare* var. Shinchunaga (6x), var. Igachikugo (6x), *A. sativa* (6x) and *A. sativa* var. Kanota (6x), the germination

Table 1. Effect of JRR-1-radiations on seedling height (cm) 10 days after sowing

Material	Dosage (per square centimeter)				
	Control	$9.2 \times 10^{10} n \text{ th}$ (1-1)	$9.2 \times 10^{11} n \text{ th}$ (1-2)	$9.2 \times 10^{12} n \text{ th}$ (1-3)	$1.8 \times 10^{12} n \text{ res}$ (1-4)
<i>Triticum monococcum</i> 2x	11.1	8.2 (73.8)*	6.6 (59.5)*	0.2 (1.8)*	1.0 (9.0)*
<i>T. dicoccum</i> 4x	13.4	12.5 (93.8)	12.9 (96.3)	1.1 (8.2)	8.4 (62.6)
<i>T. persicum</i> 4x	11.5	13.4 (116.5)	13.7 (119.0)	1.3 (11.3)	9.7 (84.3)
<i>T. vulgare</i> Shin. 6x	12.2	12.9 (105.7)	12.2 (100.0)	2.1 (17.2)	7.8 (63.9)
<i>T. vulgare</i> Iga. 6x	11.5	12.8 (111.2)	12.2 (106.0)	1.3 (11.3)	8.4 (73.0)
<i>Avena strigosa</i> 2x	8.0	7.5 (93.8)	7.2 (90.0)	0.1 (1.3)	3.0 (37.5)
<i>A. strigosa</i> 4x	6.4	6.0 (93.8)	8.4 (131.1)	0.6 (9.4)	5.8 (90.7)
<i>A. sativa</i> 6x	9.6	8.7 (90.7)	9.5 (98.9)	1.5 (15.6)	6.6 (68.8)
<i>A. sativa</i> Kan. 6x	11.8	10.5 (89.0)	10.8 (91.6)	0.9 (7.6)	8.1 (68.6)

* Figures in parentheses are % of control

Table 2. Effect of JRR-1-radiations on seedling height (cm) 50~60 days after sowing

Material		Dosage (per square centimeter)			
		Control	$9.2 \times 10^{10}n$ th (1-1)	$9.2 \times 10^{11}n$ th (1-2)	$1.8 \times 10^{12}n$ res (1-4)
<i>Triticum monococcum</i>	2x	27.0	23.2 (85.9)*	18.5 (68.5)*	— —
<i>T. dicoccum</i>	4x	26.1	26.2 (100.3)	27.7 (106.1)	18.3 (70.2)*
<i>T. persicum</i>	4x	24.3	27.5 (113.1)	27.0 (111.0)	13.3 (54.8)
<i>T. vulgare</i> Shin.	6x	29.9	31.0 (103.6)	29.1 (97.4)	20.4 (68.3)
<i>T. vulgare</i> Iga.	6x	29.8	32.3 (108.3)	33.8 (113.4)	23.1 (77.5)
<i>Avena strigosa</i>	2x	26.4	24.4 (92.5)	27.8 (105.3)	11.4 (43.2)
<i>A. strigosa</i>	4x	27.4	26.4 (96.4)	28.8 (105.0)	23.1 (84.4)
<i>A. sativa</i>	6x	30.5	28.2 (92.5)	29.6 (97.1)	23.8 (78.1)
<i>A. sativa</i> Kan.	6x	23.0	23.0 (100.0)	24.3 (105.6)	20.1 (87.5)

* Figures in parentheses are % of control

rates were as high as 90.0~100.0% even by the irradiation with $9.2 \times 10^{12}n$ th/cm².

At 10 days after sowing no reduction in seedling height was observed in the materials irradiated with $9.2 \times 10^{11}n$ th/cm² or lower dosages, with an exception of *T. monococcum* which was highly sensitive. A clear decrease was generally noted at the dosage of $9.2 \times 10^{12}n$ th/cm². A similar effect, though much smaller, was produced by $1.8 \times 10^{12}n$ res/cm² irradiation (Table 1). Table 2 shows the further data on the seedling height 50~60 days after sowing although all the seedlings from the seeds irradiated with $9.2 \times 10^{12}n$ th/cm² and those of *T. monococcum* irradiated with $1.8 \times 10^{12}n$ res/cm² had died before the measurement was made. These results show the similar tendency of radiation effects as those seen in Table 1.

The length and width of the first, second and third leaf-blades were measured 50~60

Table 3. Effect of JRR-1-radiations on length of leaf-blades 50~60 days after sowing

Material		Leaf order	Dosage (per square centimeter)			
			Control	$9.2 \times 10^{10}n$ th (1-1)	$9.2 \times 10^{11}n$ th (1-2)	$1.8 \times 10^{12}n$ res (1-4)
<i>Triticum monococcum</i>	2x	1st	100.0	84.3	68.6	—
		2nd	100.0	81.5	60.3	—
		3rd	100.0	82.0	65.1	—
<i>T. dicoccum</i>	4x	1st	100.0	101.6	100.0	69.3
		2nd	100.0	101.0	100.5	48.4
		3rd	100.0	98.5	97.9	37.8
<i>T. vulgare</i> Shin.	6x	1st	100.0	100.9	102.5	65.2
		2nd	100.0	102.0	95.9	49.7
		3rd	100.0	97.0	99.1	57.3
<i>Avena strigosa</i>	2x	1st	100.0	96.5	97.7	47.6
		2nd	100.0	96.4	89.9	39.1
		3rd	100.0	90.3	91.8	38.5
<i>A. strigosa</i>	4x	1st	100.0	103.7	107.5	72.5
		2nd	100.0	100.0	98.0	70.8
		3rd	100.0	96.1	99.6	70.1
<i>A. sativa</i> Kan.	6x	1st	100.0	94.5	98.2	75.1
		2nd	100.0	94.3	97.5	72.6
		3rd	100.0	97.7	98.3	76.0

days after sowing when the third leaves had stopped elongation (Tables 3 and 4). It can generally be said that both length and width of leaf-blades decreased with increasing dosage so far examined. Furthermore it can be noticed that each species showed a characteristic radiosensitivity, i. e., *T. monococcum* was of most sensitive, followed in order by *A. strigosa* and *T. dicoccum* or *T. vulgare*, and *A. sativa* was most resistant. In the other words, polyploids showed a higher radioresistance than diploids, and *Avena* was more resistant than *Triticum*.

Table 4. Effect of JRR-1-radiations on width of leaf-blades 50~60 days after sowing

Material	Leaf order	Dosage (per square centimeter)			
		Control	$9.2 \times 10^{10}n$ th (1-1)	$9.2 \times 10^{11}n$ th (1-2)	$1.8 \times 10^{12}n$ res (1-4)
<i>Triticum monococcum</i> 2x	1st	100.0	78.4	75.7	—
	2nd	100.0	79.3	69.0	—
	3rd	100.0	80.0	67.5	—
<i>T. dicoccum</i> 4x	1st	100.0	104.5	97.8	79.5
	2nd	100.0	110.8	108.0	59.5
	3rd	100.0	93.8	100.0	39.6
<i>T. vulgare</i> Shin. 6x	1st	100.0	93.9	93.9	77.5
	2nd	100.0	100.0	92.8	53.7
	3rd	100.0	104.0	96.0	36.0
<i>Avena strigosa</i> 2x	1st	100.0	93.8	93.8	78.2
	2nd	100.0	96.6	93.2	62.1
	3rd	100.0	93.7	85.1	38.3
<i>A. strigosa</i> 4x	1st	100.0	109.7	90.4	80.6
	2nd	100.0	105.8	91.2	79.4
	3rd	100.0	104.0	92.0	74.0
<i>A. sativa</i> Kan. 6x	1st	100.0	101.9	101.9	84.6
	2nd	100.0	92.8	97.6	83.0
	3rd	100.0	101.9	100.0	67.9

In some cases irradiated with $9.2 \times 10^{11}n$ th/cm² or $1.8 \times 10^{12}n$ res/cm² the length of the second and third leaf-blades were clearly shorter than those of the first leaf-blades. The similar situation was found for the width of leaf-blades (Tables 3 and 4). Further comparisons were made with respect to the size of leaf-blades (length×width) of the irradiated seedlings and the controls (Table 5). The size of the first, second and third leaf-blades in plants irradiated with $9.2 \times 10^{11}n$ th/cm² or $1.8 \times 10^{12}n$ res/cm² were in some cases smaller than those of the control plants. The data further suggest that the radiosensitivity increased with the progress of leaf order. That is, the third leaf was most sensitive and extremely reduced in its size, while the first leaf was most tolerant. This relation was prominent with the dosage of $1.8 \times 10^{12}n$ res/cm².

All seedlings of *T. monococcum* died 50~60 days after sowing by the irradiation of $1.8 \times 10^{12}n$ res/cm² and also those of the other species did by $9.2 \times 10^{12}n$ th/cm² as mentioned above. In all of the other cases irradiated, the survival rates did not show any significant differences from those of the controls. From these facts it is evident that LD-50 for every species falls into 10^{12} order of thermal neutron fluxes per square centimeter.

Irradiation experiment II

The second irradiation experiment was carried out in January, 1959. Dry seeds of

Table 5. Index of leaf-blade size (length×width) calculated from Tables 3 and 4

Material	Leaf order	Dosage (per square centimeter)			
		Control	$9.2 \times 10^{10} n$ th (1-1)	$9.2 \times 10^{11} n$ th (1-2)	$1.8 \times 10^{12} n$ res (1-4)
<i>Triticum monococcum</i> 2x	1st	100.0	65.3	51.9	—
	2nd	100.0	64.6	41.6	—
	3rd	100.0	65.6	44.0	—
<i>T. dicoccum</i> 4x	1st	100.0	106.2	97.8	55.1
	2nd	100.0	111.9	108.6	28.8
	3rd	100.0	92.4	97.9	15.0
<i>T. vulgare</i> Shin. 6x	1st	100.0	94.8	96.4	50.5
	2nd	100.0	102.0	89.0	26.7
	3rd	100.0	100.9	95.1	10.6
<i>Avena strigosa</i> 2x	1st	100.0	90.5	91.6	37.2
	2nd	100.0	92.2	83.8	24.2
	3rd	100.0	84.6	78.1	14.7
<i>A. strigosa</i> 4x	1st	100.0	113.7	97.3	58.5
	2nd	100.0	105.8	89.4	56.2
	3rd	100.0	100.0	91.6	51.9
<i>A. sativa</i> Kan. 6x	1st	100.0	96.3	100.0	63.5
	2nd	100.0	87.5	95.2	60.3
	3rd	100.0	99.5	98.3	51.6

four *Triticum* species, one *Aegilops* species, and five *Avena* species were irradiated with the following dosages of thermal neutrons with other contaminating radiations in the beam hole No. 16 :

Exposure number	Thermal neutrons ($\times 10^{11} n$ th/cm ²)	Resonance neutrons ($\times 10^{11} n$ res/cm ²)	Gamma-rays (r)
(2-1)	7.9	1.6	360
(2-2)	16.0	3.2	710
(2-3)	32.0	6.3	1400
(2-4)	63.0	13.0	2800
(2-5)	92.0	18.0	4100
(2-6)	—	4.8	1100
(2-7)	—	9.6	2200
(2-8)	—	11.0	2500
(2-9)	—	22.0	4900

Seeds in (2-1)~(2-5) were irradiated without any filter, but those in (2-6)~(2-9) with 0.5 mm Cd-filter when the reactor was being operated at 5 kW, excepting for (2-5) and (2-9) which were exposed at 40 kW. On the other hand, the same materials were treated with 10~40 kr of X- and gamma-rays in order to compare with the effects of JRR-1-radiations. The X-irradiation was performed under 200 kV, 19 mA, with 1.0 mm Al-filter, giving 408 r per minute, at the Faculty of Agriculture, Kyoto University. The gamma-irradiation from ⁶⁰Co-source was conducted at the Institute for Chemical Research, Kyoto University.

For each dosage of neutron-, X-, or gamma-treatment, 50 seeds were used for each species. After treatments these seeds were sown and grown in wooden flats as in the first experiment, and survival rates 30 and 100 days after sowing were studied. Based on these studies LD-50 in various species was determined. Table 6 shows LD-50 obtained for neutrons, X-rays and gamma-rays.

The differences in LD-50 among the ten species used became apparent 100 days after

Table 6. LD-50 30 and 100 days after sowing

Material	Thermal neutrons* ($\times 10^{11} n$ th/cm ²)		Resonance neutrons* ($\times 10^{11} n$ res/cm ²)		X-rays (kr)	Gamma-rays (kr)
	30 days	100 days	30 days	100 days	100 days	100 days
<i>Triticum monococcum</i> (2x)	32~63	16~32	9.6~11	4.8~9.6	10~20	10~20
<i>T. dicoccum</i> (4x)	63~92	32~63	11~22	9.6~11	20~30	20~30
<i>T. vulgare</i> Shin. (6x)	63~92	32~63	11~22	9.6~11	20~30	20~30
<i>T. vulgare</i> Iga. (6x)	63~92	32~63	11~22	9.6~11	20~30	20~30
<i>Aegilops squarrosa</i> (2x)	—	32~63	9.6~11	4.8~9.6	10~20	10~20
<i>Avena strigosa</i> (2x)	63~92	32~63	11~22	9.6~11	20	20
<i>A. strigosa</i> (4x)	63~92	63~92	11~22	11	20~30	20~30
<i>A. barbata</i> (4x)	—	63~92	11~22	4.8~9.6	10~20	10~20
<i>A. sativa</i> (6x)	63~92	63~92	11~22	11	30	30~40
<i>A. sativa</i> Kan. (6x)	63~92	63~92	11~22	11	20~30	20~30

* Other radiations are contaminating (see page 243)

sowing. *Avena* and probably *Aegilops* possess a higher resistance for neutrons than *Triticum* (Table 6). It can also be seen from the table that tetraploid and hexaploid species have a higher resistance to radiations than the diploid species in the same genera. Nearly the same results were obtained by the irradiations with X-rays and gamma-rays from ⁶⁰Co, with an exception of a tetraploid *Avena* species, *A. barbata*. The present data for gamma-rays agreed very well with the results obtained previously by NISHIYAMA, OKAMOTO and MARUYAMA (1959).

Discussion

Dosages of thermal neutrons which were high enough to reduce the seedling height, the length and width of leaf-blades as well as the survival rate did not disturb the seed germination, although the sprouts were not permitted to grow up longer than 5 mm and were soon killed. Similar high germination rates (more than 80%) in dry seeds of di-, tetra-, and hexaploid species of *Triticum* and *Avena* irradiated with 5~70 kr of gamma-rays from ⁶⁰Co were reported by NISHIYAMA, OKAMOTO and MARUYAMA (1959). More surprising facts were obtained in a preliminary experiment of this study in which more than 70% of dry seeds of the same materials germinated even when irradiated with 500 kr of X-rays or $2.3 \times 10^{15} n$ th/cm² of radiations in No. 16 hole of JRR-1 although of course they died soon. Therefore the germination rate appears to be an inappropriate measure to show the radiosensitivity.

Diploid species, especially of *Triticum*, suffered more severe damages on their seedling growth by neutron irradiation than polyploids. Tetraploid and hexaploid species were of nearly the same radiosensitivity, although the data for *Avena* were not yet appropriate in the present experiments. Seedlings of *Triticum* and *Avena*, excepting *T. monococcum* (2x), were not damaged at all in their growth by $9.2 \times 10^{11} n$ th/cm² irradiation, but suffered a slight disturbance by $1.8 \times 10^{12} n$ res/cm² and a severe disturbance by $9.2 \times 10^{12} n$ th/cm². From the above mentioned dosimetry in JRR-1 it is known that these dosages are contaminated with other radiations as follows:

9.2×10^{11} n th/cm² being contaminated with 1.8×10^{11} n res/cm² and 410 r gamma-rays
 9.2×10^{12} n th/cm² being contaminated with 1.8×10^{12} n res/cm² and 4100 r gamma-rays
 1.8×10^{12} n res/cm² being contaminated with 4100 r gamma-rays

Thus, from the experimental data mentioned above, it is difficult to know the biological effects owing to the thermal or resonance neutrons themselves.

KONZAK and SINGLETON (1952) reported that tetraploids (including autotetraploids) and hexaploids were less injured than their related diploids, when seeds of wheat, oats, rye, and maize were exposed to thermal neutrons at Brookhaven National Laboratory, U.S.A. They stated further that tetraploid wheats and oats were of higher resistance to thermal neutrons than hexaploids. SCHMIDT and FROLIK (1951) informed clear decrease of seedling height in maize by $8.4 \sim 16.8 \times 10^{12}$ n th/cm² irradiation on the seeds, using the heavy water pile of the Argonne National Laboratory, U. S. A. EHRENBORG and NYBOM (1954) also treated barley seeds with thermal neutrons in the Norwegian nuclear reactor at Kjeller, Norway, and found distinct decrease of seedling height at the dosage of 1.4×10^{12} n th/cm². In rice plants, $3 \sim 5 \times 10^{13}$ n th/cm² obtained from the thermal column of the nuclear reactor of Brookhaven National Laboratory was enough to reduce seedling height to 50% of the control (MATSUO *et al.*, 1958). Using the beam hole No. 16 of JRR-1, MASIMA and KAWAI (1960) found that the dose required to reduce the seedling height of rice plants to 50% of the control was $1.08 \sim 1.26 \times 10^{13}$ n th/cm², which might include resonance neutrons. The difference between these two data in rice plants might be due in part to the very low cadmium ratio, 6 (JRR-1 OPERATION GROUP 1958), and the high gamma-ray contamination, $1\text{r}/2.23 \times 10^9$ n th·cm⁻² (after KONDO, 1960), of the beam hole No. 16 of JRR-1, compared with the thermal column of Brookhaven National Laboratory (cadmium ratio, 5000 ; gamma-ray contamination, $1\text{r}/1.10 \times 10^{10}$ n th·cm⁻² (after CALDECOTT 1955)). If so, the severe damage of all seedlings irradiated with 9.2×10^{12} n th/cm² in the present experiment can be understood. Another experiment was made by MATSUMURA (1961) who treated dry seeds of *T. monococcum* with thermal neutrons from the beam hole No. 7 of JRR-1, and reported that the dose of about 9.3×10^{12} n th/cm² reduced to 80% of the control in the seedling height two weeks after sowing. This result does not agree with the present one in which seedlings of the same species were extremely damaged (reduced in height to 1.8% of the control 10 days after sowing) even by the irradiation of 9.2×10^{12} n th/cm². Such different biological effects were clearly observed between the treatments made using No. 7 hole and No. 16 hole, in the same dose irradiation on *T. monococcum* and *A. strigosa* (NISHIYAMA, *et al.* unpublished). This difference is probably ascribed to (1) the different dose rates between the two holes, 2.0×10^8 n th/cm²·sec being the highest dose rate in No. 7 and 4.16×10^{11} n th/cm²·sec in No. 16, both at 40 kW (KONDO, 1960), and (2) the different cadmium ratio which is considerably higher in No. 7 than the ratio in No. 16 (JRR-1 OPERATION GROUP, 1958).

Both length and width of the first to third leaf-blades decreased in response to the radiation dosages, the first leaf being most tolerant and the third leaf most susceptible to thermal neutrons (Tables 3, 4, and 5). Similar results were obtained by the irradiation of gamma-rays from ⁶⁰Co on the same materials (NISHIYAMA, OKAMOTO and MARUYAMA

1959). From these results it can be said in general that the plants from irradiated seeds were characteristic of shorter and narrower leaves and that the degree of these effects varied according to the leaf order, leaves in higher order being more strongly damaged. That is to say, the less the degree of the organ development, the greater would be the disturbance by radiations.

LD-50 100 days after sowing were measured in regard to neutrons, X-rays, and gamma-rays (Table 6). LD-50 in diploid wheat and oats were lower than those of the related tetra- and hexaploids. There was found no distinct difference in LD-50 between tetraploids and hexaploids in these genera. In comparing LD-50 100 days after sowing, the effect of $6.3 \times 10^{12} n \text{ th/cm}^2$ irradiation in the beam hole No. 16 of JRR-1 nearly corresponds to that of 30 kr of X- or gamma-rays (see also NISHIYAMA, OKAMOTO and MARUYAMA 1959). Namely, 1r of X- or gamma-rays has an effect equivalent to about $2.1 \times 10^8 n \text{ th/cm}^2$ on survival rate.

From the data obtained by CALDECOTT *et al.* (1952, '54) and CALDECOTT (1955), it can be calculated that about $5.7 \times 10^8 n \text{ th/cm}^2$ have the 1r equivalent effect of X-rays on the survival rate at maturity of barley. On the other hand, MASIMA and KAWAI (1960) stated that the dosage of $4.0 \times 10^8 n \text{ th/cm}^2$ (which might include resonance neutrons) was equivalent to 1r of X-rays in effect on the survival rate at maturity of rice plants. The differences in the results obtained by the above workers could be ascribed to the possibly different efficiencies of the generators of neutrons or X-rays used in their experiments.

Besides, CALDECOTT (1955), MATSUO *et al.* (1958), MASIMA and KAWAI (1960), MATSUMURA (1961) and others reported the thermal neutron doses which were equivalent to 1r of X- or gamma-rays in effects on growth inhibit, chlorophyll mutation frequency and *etc.*

Summary

Dry seeds of di-, tetra-, and hexaploid species of *Triticum* and *Avena* and of a diploid species of *Aegilops*, were exposed to thermal neutrons from the beam hole No. 16 of JRR-1, and their biological effects were investigated.

The seed germination was not affected by the dose of $9.2 \times 10^{11} n \text{ th/cm}^2$ or $1.8 \times 10^{12} n \text{ res/cm}^2$ (obtained by using 0.5 mm Cd-filter to exclude thermal neutrons), but was clearly disturbed by $9.2 \times 10^{12} n \text{ th/cm}^2$, excepting hexaploid species. Seedling heights of diploid species decreased distinctly by $1.8 \times 10^{12} n \text{ res/cm}^2$ and extremely by $9.2 \times 10^{12} n \text{ th/cm}^2$, but tetra- and hexaploid species were more tolerant than diploids. Moreover, the experiments indicated that *Avena* is generally more resistant than *Triticum*.

Both length and width of the first, second, and third leaf-blades were reduced by certain dosages, the first leaf being most tolerant and the third most sensitive. This fact may suggest that leaves in different developmental stages show different responses to radiations.

LD-50 for thermal neutrons, X-rays and gamma-rays were determined for every species. Comparing the survival rate 100 days after sowing, the dose of about $2.1 \times 10^8 n \text{ th/cm}^2$ of thermal neutrons (plus other contaminating radiations) in JRR-1 was calculated

to have the effect equivalent to 1r of X- or gamma-rays.

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植物における放射線生物学的研究

第6報 コムギおよびエンバク乾燥種子に対する原子炉 (JRR-1) 放射線の影響

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日本の最初の原子炉である、日本原子力研究所東海研究所の第一号原子炉 (JRR-1) の放射線が、植物体を与える影響と、 γ 線やX線による影響とを比較調査した。この実験では JRR-1 の No. 16 実験孔 (気送管) を使用したが、この実験孔での主な放射線は熱中性子であつて、このほかいくらかの共鳴中性子、速中性子および γ 線が混在している。

実験 I ではコムギ 5 種およびエンバク 4 種の乾燥種子に、0.5 または 40 kW 運転時に $9.2 \times 10^{10} \sim 9.2 \times 10^{12}$ n th/cm² の熱中性子照射を行ない、また 0.5 mm のカドミウム・フィルターを用いて熱中性子を除くことによつて 1.8×10^{12} n res/cm² の共鳴中性子を照射した。もちろん前者には共鳴中性子、速中性子および γ 線が、後者には速中性子と γ 線が混在していた。種子の発芽率は 9.2×10^{11} n th/cm² または 1.8×10^{12} n res/cm² の照射ではほとんど低下せず、 9.2×10^{12} n th/cm² 照射では特に二倍種の発芽率が低下した。播種後 10 日目の芽生の草丈は 1.8×10^{12} n res/cm² 照射によつてやや低下し、 9.2×10^{12} n th/cm² 照射では極端に低下した。この場合、二倍種は四倍種および六倍種に比較して放射線感受性が高く、またコムギは一般にエンバクより感受性が高かつた。次に芽生の第 1 葉から第 3 葉の幅と長さに対する放射線の影響を調査すると、葉位が進むほど葉身の

幅や長さが極端に減少し、感受性が葉位に従つて高まるということが認められた。このことから同種器官の放射線感受性が照射時におけるその器官の分化の程度によつてことなることが明らかである。すなわち、分化の程度が低いほど感受性が高いことが知られた。

実験 II ではコムギ 4 種、エギロプス 1 種およびエンバク 5 種の乾燥種子に、同じ実験孔で 5 または 40 kW 運転時に $7.9 \times 10^{11} \sim 9.2 \times 10^{12}$ n th/cm² の熱中性子照射と $4.8 \times 10^{11} \sim 2.2 \times 10^{12}$ n res/cm² の共鳴中性子照射を行ない、LD-50 の決定を試みた。同時にこれらの材料に対する γ 線およびX線の LD-50 を求め、中性子のそれと比較した。その結果、二倍種における LD-50 は四倍種および六倍種における LD-50 よりもかなり低く、またコムギにおける LD-50 はエンバクにおける LD-50 よりも一般に低いことが認められ、芽生の高さの場合とよく一致した。なお、この実験から、この実験孔の 2.1×10^8 n th/cm² の熱中性子線量 (十他の混在放射線線量) が、生存率に対して、 γ 線やX線の 1r とほぼ同程度の効果を持つことが明らかにされた。

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