Radiosensitivity in Plants

I. Relation between the water content of some crop seeds and their sensitivity to different doses of X-rays and 7-rays

Taira Katayama and Tsutsumi Nagamatsu

(Plant Breeding Laboratory, Faculty of Agriculture, Kyushu University)

Synopsis. Sensitivity of dormant seeds to various dosages of radiation was at a minimum when they contained from about 12 to 18 % water, except for rape seeds. Sensitivity of dormant seeds of various plants to radiation is increased by either a low or a high water content.

Since Stadler (1928) induced mutations in barley by X-rays, it has been accepted by numerous workers that a positive correlation exists between the water content of biological systems and their X-ray sensitivity. However, Ehrenberg and Nybom (1954) and Caldecott (1954) reported that, actually, an inverse relationship existed between the X-ray sensitivity and the water content of dormant barley seeds which had reached weight equilibrium at different relative humidities. The same phenomenon was also observed in oat seeds (Abrams and Frey 1957), rice seeds (Kawai et al. 1962, Nagamatsu and Katayama 1959, 1963) and Japanese red pine seeds (Oba 1961). It is of interest, therefore, to determine whether this response of seeds to X-rays can be considered as a generality.

This paper is a further contribution toward attempting to establish this generality.

Materials and Methods

Rice Dormant seeds of rice varieties Norin-Nos. 22 and 40, produced in 1959 at the University Farm, were irradiated by X-rays in 1960. Seeds placed in a thin layer in a petri dish were exposed to the dosages of 0, 15, 20 and 25 kR, at 180 kVp, 20 mA applied at a distance of 26 cm without filter. The dose rate was 1,014 R/min. After irradiation the seeds were soaked in water in petri dishes for 3 days at 25°C. The seeds were then sown in soil contained in a box and held under nursery condition. The height of seedling and survival were used to measure the effects of treatment.

Wheat The seeds of the variety Norin-No. 29, produced at the University Farm in 1959, were exposed to the X-rays in 1960 at 180 kVp, 20 mA, from a distance of 26 cm without filter, giving approximately 900 R/min. After irradiation the seeds were sown in petri dishes and held in an incubator regulated at 20°C. Measurements were taken on height of individual seedling and survival.

Soybean The seeds of the variety Kogane-Natsu-Daizu, produced at the Saga Soybean Breeding Center, were irradiated in 1960 by X-rays at 180 kVp, 20 mA, from a distance of 26 cm without filter to give approximately 900 R/min. After irradiation the seeds were

Received Jan. 5, 1965
Table 1. Chemicals used to control seeds water content

<table>
<thead>
<tr>
<th>No. of desiccator</th>
<th>Stored in desiccator at room temperature over</th>
<th>Expected relative humidity of air(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H₂O</td>
<td>100.0</td>
</tr>
<tr>
<td>2</td>
<td>NH₄H₂PO₄ Satu.</td>
<td>Ca. 92.5</td>
</tr>
<tr>
<td>3</td>
<td>K₂Cr₂O₇</td>
<td>86.4</td>
</tr>
<tr>
<td>4</td>
<td>NaCl</td>
<td>75.4</td>
</tr>
<tr>
<td>5</td>
<td>NH₄NO₃</td>
<td>64.0</td>
</tr>
<tr>
<td>6</td>
<td>K₃PO₄·4H₂O</td>
<td>55.0</td>
</tr>
<tr>
<td>7</td>
<td>K₂CO₃</td>
<td>44.0</td>
</tr>
<tr>
<td>8</td>
<td>MgCl₂·6H₂O</td>
<td>35.0</td>
</tr>
<tr>
<td>9</td>
<td>CaCl₂</td>
<td>32.0</td>
</tr>
<tr>
<td>10</td>
<td>K₂H₇COOH</td>
<td>22.0</td>
</tr>
<tr>
<td>11</td>
<td>CaCl₂ Dry</td>
<td>—</td>
</tr>
<tr>
<td>12</td>
<td>P₂O₅</td>
<td>—</td>
</tr>
<tr>
<td>13</td>
<td>H₂SO₄ Conc.</td>
<td>—</td>
</tr>
</tbody>
</table>

sown in soil contained in a wooden box.

Rape Two varieties Abura-Masari and Kyushu-No. 47, produced at the Fukuoka Rape Breeding Center in 1960, were irradiated with ⁶⁰Co. The former variety contained a higher percentage of oil than the latter. Prior to irradiation the seeds were stored in desiccators over substances with different vapor pressures for 10 months (from Nov. 17, 1960 to Sep. 25, 1961). The irradiation was at the dosages of 0, 50, 107 and 160 kR. After irradiation the seeds were sown in petri dishes and held in an incubator regulated at 20°C for 2 days to hasten germination.

Prior to irradiation the water content of seeds of various crops was modified by storage at different relative humidities (produced by substances contained in desiccators as shown in Table 1) until they reached weight equilibrium. To determine the water content of the seeds, samples were weighed before and after drying in an electric oven for one day at 105°C.

Results

Rice Nearly identical results were obtained from both varieties used. Data of results reported are, however, mainly on Norin-No. 22. There were no differences in germination percentages among irradiated seeds of various water content, except when the content was more than 18% or less than 11%. The highest survival percentage following any dose of irradiation was among seedlings which sprouted from seeds that contained between 11 and 18% water. No seedlings were obtained from seeds that contained more than 18% or less than 8% water. Seedling height at 19 days after X-ray irradiation is given in Fig. 1. It shows that the seedling height decreased with the increase in dosage of X-rays. The greatest resistance of dormant seeds to X-rays was observed at a water content of between 12 and 18%.

Wheat In dormant seeds with 5 to 15% water, regardless of the dosage of X-rays, there was no difference in germination percentage. From the data on seedling height at 7 days after X-ray irradiation, it seemed that the radiation resistance decreased at the dosage increased (Fig. 2). At 20 kR the seeds with a water content of 13 to 18% were more resistant to irradiation than at other percentages, and at 40 kR they were also somewhat more resistant with a water content of about 12%.

Soybean Most dormant seeds with high water content, such as at 30.4 and 38.0%, failed to germinate, even with no irradiation. On the other hand, the seeds with a lower water content showed relatively good germination, especially when the content
was 5 to 16\%.

The highest survival percentage at 37 days after X-ray irradiation was in seeds with a water content of 2 to 17\% for 0 kR, 5 to 21\% for 15 kR and 12 to 17\% for 30 kR, respectively. Seedling height at 14 days after X-ray irradiation is given in Fig. 3. From Fig. 3, the dormant seeds with a water content of 12 to 20\% showed a high resistance to 15 kR of X-rays, and similarly dormant seeds with 10 to 21\% water content showed a high resistance to 30 kR.

**Rape**

In general, rape showed high resistance to radiation

(Kyushu-No. 47) Regardless of the dosage of \(\gamma\)-ray irradiation by \(^{60}\text{Co}\), dormant seeds of between 5 and 9\% water content showed no difference in ability to germinate. Seeds with less than 5\% water content or more than 9\%, especially the latter, showed decreased germination percentage. Similar results were obtained on the seedling height at 10 days after \(\gamma\)-ray irradiation. Seeds with less than 5\% water content or more than 9\% decreased in seedling height, and those with more than 10\% died soon after germination (Fig. 4).

(Abura-Masari) For the dosage of 0 to 160 kR of \(^{60}\text{Co}\), the variety showed but little difference in germination percentage of seeds between 2 and 12\% water content. The seedling height of the untreated control decreased as the water content increased from 2 to 9\% and fell sharply when it was more than 10\%. The seedling height following irradiation decreased with the increase in dosage of \(\gamma\)-rays, which was especially shown when the water content of the dormant seeds was less than 5\% or more than 9\%.

**Discussion**

This experiment was intended to obtain as much data on the response of dormant
seeds with various water contents to X-rays and γ-rays. The results are summarized in Fig. 5. From a comparison of all the data presented, it seems fair to conclude that the sensitivity of most dormant seeds to irradiation is at a minimum when they contain about 12 to 18% water (5 to 8% for rape) and they approach the maximum sensitivity when they contain less than 12% (5% for rape) or more than 18% (8% for rape) water.

For many years, it has been recognized that seeds with a high water content are more sensitive to X-ray irradiation than those with a low water content. And it is considered by many workers that the increased radiosensitivity of the seeds with a high water content results largely from the nature and frequency of the radical species formed along the tracks of ionizing electrons.

Recently in barley, relationship between dormant seeds with different water contents and radiation sensitivity has been studied in detail (Caldecott 1954, 1955a, 1955b, Ehrenberg 1955a, 1955b and Ehrenberg and Nyblom 1954). Ehrenberg and Nyblom (1954) found that seeds with an 8.6% water content showed lowest sensitivity. In barley seeds Ehrenberg (1955a, 1955b) reported that the effectiveness of sparsely ionizing radiation decreased as the water content of seeds increased from 7 to 20%.

Caldecott (1954, 1955a, 1955b) also described that barley seeds with an 8 to 16% water content were most resistant to X-ray inhibition. In Agrostis stolonifera, Ehrenberg and Ehrenberg (1959) observed that the same amount of free radicals was primarily produced in the seeds independently of their water content and that the radicals remain unchanged in the driest samples but an increasing proportion of them decayed as the
water content increased. CONGER and RANDOLPH (1959) found that about 2 to 3 times as many radicals were detected after irradiation of dry wheat germ (1.5% water content) as were detected after irradiation of wet germ (8.5%).

EHRENBERG and NYBOM (1954) suggested that hydrated dormant seeds produced a protective substance to radiation. From the fact that there was not a 1-to-1 relationship between the water content of seeds and their sensitivity to X-rays, CALDECOTT (1954) suggested that reduced seedling height resulting from X-irradiation was not simply related to the production of active radicals in the presence of water.

In general, production and decay of radicals were influenced by the environmental conditions of irradiation, various biological compounds (amino acid, proteins etc.) and storage. Free radicals induced by irradiation were quite stable and lasted much longer in drier seeds than in those with a high water content where they decayed very rapidly to a semiconstant level (EHRENBERG and EHRENBERG 1959, CONGER and RANDOLPH 1959). Moreover, in a case where the seeds contain still more water, it was supposed that the sensitivity may be increased by a new type of chemical reaction following the metabolic activity of the organism at the higher water content (EHRENBERG et al., cited from OBA 1961).

**Summary**

1. Relationship between the water content of dormant seeds of several plants and their sensitivity to X-rays and γ-rays was studied.
2. Sensitivity of dormant seeds to various radiations was at a minimum when they contained from about 12 to 18% water, except for rape seeds.
3. Resistance of dormant rape seeds to $\gamma$-rays was at a maximum when they contained from 5 to 8% water.

4. In general, sensitivity of dormant seeds of various plants to radiation is increased by either a low or a high water content.

Literature cited


CALDECOTT, R.S. 1954. Inverse relationship between the water content of seeds and sensitivity to X-rays. Science 120 : 809~810.


植物における放射線感受性

I. 数種作物の種子含水量と放射線感受性に関する研究

片山 平・永松土巳

(九州大学農学部)

イネ、コムギ、ダイズ、ナタネを材料として、各種の含水量を含む休眠種子にX線、$^{60}$Co $\gamma$線を照射し、種子含水量と放射線感受性との関係を明らかにした。結果は第5図にまとめられたように、本実験の範囲では、種子含水量12~18%（ナタネでは5~8%）の範囲において放射線感受性が低く、含水量がこれより少くても多くても感受性は高いことが認められた。この傾向は、従来得られた結果とよく一致することを示すものである。